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The Mechanistic Autonomy of Nature

By

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"This world, which is the same for all, no one of gods or men has made; but it was ever, is now, and ever shall be an ever-living fire, with measures kindling, and measures going out."

HERAKLEITOS, 540-475 B. C.

"If, therefore, anyone wishes to search out the truth of things in serious earnest, he ought not to select one special science; for all the sciences are conjoined with each other and interdependent; he ought rather to think how to increase the natural light of reason, not for the purpose of resolving this or that difficulty of scholastic type, but in order that his understanding may enlighten his will to its proper choice in all the contingencies of life. In a short time he will see with amazement that he has made much more progress than those who are eager about particular ends, and that he has not only obtained all that they desire, but even higher results than fall within his expectation."

RENE DESCARTES, 1596-1650.

"The source of man's unhappiness is his ignorance of nature."

Le Systeme de la Nature by P. H. d'HOLBACH, 1770.

THE MECHANISTIC AUTONOMY OF NATURE

CHAPTER I

RATIONALISM VS. SUPERNATURALISM

"Wake! For the Sun, who scatter'd into flight
The Stars before him from the Field of Night,
Drives Night along with them from heav'n, and strikes
The Sultan's Turret with a Shaft of Light."

THE RUBAIYAT OF OMAR KHAYYAM, ♪ -1123.

"Religion is a mere castle in the air;—Theology is but the ignorance of natural causes reduced to a system;—a long tissue of fallacies and contradictions."

Le Bon Sens by JEAN MESLIER, 1678-1733.

"I have no need for the hypothesis of a God."

P. S. LAPLACE, 1749-1827.

"Is not that a strange logic which finds proof of an asserted fact in an inexplicable illustration of something else?"

History of the Conflict between Religion and Science
by J. W. DRAPER, 1811-1882.

"What the scientist calls force, energy, or nature cannot be identified with the personal, extra-mundane being that the religionist calls God. We have worn the mask long enough. We have had too much hedging and hypocrisy in the schools, and there is no longer anything to be gained by suppressing the truth. Here it is: *The modern scientist is an atheist.*" (Summarized by V. Randolph.)

Die Weltrütsel by E. H. HAECKEL, 1834-1919.

The modern scientific conception of the world differs from the more primitive notions not only in the greater abundance of details but also in the more comprehensive

and far-reaching system of natural law. Primitive man may have taken cognizance of certain relationships of cause and effect, but he probably considered these to be merely accidental uniformities with no special significance. For his welfare and protection he solicited the favor of his deities whom he considered to be fully capable of interrupting the uniformities of nature by their intervention, and the possibility that heredity and environment might have some influence upon his destiny never occurred to him. In primitive man the theological sentiment predominated, and it seems to be an undeniable fact that in the world today the most illiterate are also the most dogmatic whereas those who have most thoroughly familiarized themselves with all branches of modern science are usually atheists.

It is sometimes contended that science and religion are in disagreement on only certain minor details and that after these few remaining discrepancies have been cleared up there will be complete harmony. If this were true, then the conflict would have been ended long ago, whereas actually it has developed into a war of extermination. Those who have kept abreast with modern scientific developments have almost invariably given up their religious beliefs in whole or in part, whereas religious organizations have been sacrificing many of their most cherished and time-honored doctrines in their last desperate efforts to retain the scientifically-minded within their ranks. There may be a few exceptional cases where those who have become prominent in some specialized branch of science have carried with them the primitive religious notions of their childhoods, but skill in a particular field may be acquired without any comprehension of the broader philosophical aspects of the subject in its entirety. It is also a well-recognized fact that there are many who have dual personalities, their

minds being so compartmentalized that they can entertain mutually exclusive conceptions and attitudes.

It has also been contended that there is sufficient community of purpose in the promotion of morals and ethics to form the basis for an amicable understanding between science and religion, but the difficulty is that neither science nor religion is primarily concerned with the promotion of morals and ethics. In fact, the causing of needless misery and deprivation by fictitious representations of reward or punishment after death would be repugnant to the candidness and integrity of modern science. The principles of morals and ethics are inherent in the mechanism and organization of the animal kingdom and did not originate with the precepts of theologians. The possibility of bringing about a satisfactory understanding between science and religion in the near future seems unlikely when it is considered that the different religious faiths are still hopelessly at odds with one another, although they have much more in common among themselves than they have with science.

Religion cannot escape its encounters with science and boast of infallibility in its own particular field by pretending to be concerned only with human conduct or behavior and not with scientific questions of fact. Every phase of human activity can be traced to materialistic causes or antecedents. Every condition of human consciousness is associated with a corresponding physical or chemical condition of the body-tissues. It would therefore be impossible for religion to exercise infallible judgment over matters of human conduct without a complete understanding of the scientific background. Infallibility in matters of conduct requires omniscience, and there is no such a thing as omniscience in only a restricted group of subjects.

Efforts have also been made to establish some sort of agreement by mutual concessions and compromises, as

for example by admitting that Divine creation may have been by evolution, and Divine sustentation by operation of the laws of nature. Such a dualistic theory might have some merit if the course of evolution were random and arbitrary and the laws of nature mutable and capricious. However, although our knowledge of details is still very incomplete, yet there is every indication that the process of evolution, and of biological behavior generally, is governed strictly by the laws of physics and chemistry and that the latter have their ultimate basis in the unalterable principles of geometry and statistical mechanics. The theory of Divine ordination must therefore be excluded as far as natural phenomena are concerned because we cannot attribute such phenomena to Divine agencies which must be presumed to have freedom of action, and at the same time say that they were brought about by necessity through the operation of immutable laws of nature.

Supernaturalism is the rock on which all efforts to harmonize science and religion come to grief. Rationalism and supernaturalism are mutually exclusive. The rationalistic systematization of nature by modern science has been so thorough as to leave no room for supernaturalism, whereas religion without supernaturalism is inconceivable. Without the enchanting guise of supernaturalism and its glamor of ritual and ceremony, religion would soon lose its hold on the multitudes. Religion without supernaturalism has never existed nor ever could exist, except in the imaginations of confused idealists. To rationalize religion would be to destroy it because there would then be nothing left with which to bewilder and overawe the masses.

The conflict between science and religion is not so much on isolated questions of fact such as the age of the earth or the ancestry of man, as in criteria of knowledge and methods of reasoning. Religion follows dogma and

tradition whereas science follows observation and experience. Religion idolizes authority whereas science demands proof. Religion cultivates the emotional thrill whereas science warns against being swayed by preconceived desires or prejudices. In short, the mental attitude which is necessary to make a good religionist is exactly the antithesis of the mental attitude which is necessary to make a good scientist, and the conflict will not be ended until there has been complete abandonment of the one or the other.

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CHAPTER II

THE ULTIMATE GROUNDWORK OF NATURE

"I do not accept or desire any other principle in physics than in geometry or abstract mathematics, because all the phenomena of nature may be explained by their means."

RENE DESCARTES, 1596-1650.

"To tell us that every Species of Things is endowed with an occult specific Quality by which it acts and produces manifest effects, is to tell us nothing; but to derive two or three Principles of Motion from Phenomena and afterwards to tell us how the Properties and Actions of all corporeal Things follow from these manifest Principles would be a very great step in Philosophy, though the Causes of those Principles were not yet discovered."

ISAAC NEWTON, 1642-1727.

"The world has always been; its existence is necessary; it is its own cause.—Matter moves by its own energy, as a necessary consequence of its own heterogeneity. The diversity of motion or modes of action constitute alone the diversity of substances."

Le Bon Sens by JEAN MESLIER, 1678-1733.

"For you who seek reality as something characteristic of certain concepts in physics as distinct from others will find that such reality is but the will-o'-the-wisp of philosophy. You may think you have it in your hand but will find that you have merely the shadow of something else. You will pursue that something else; you will touch it, and again it will feel real until you find that your consciousness of its touch is no more than the tingle of your blood as your hands clasp upon it."

Reality in Physics, by W. F. G. SWANN, (1932).

We are sometimes confronted with the suggestion that our minds may be so constituted that even if the true interpretations of natural phenomena were offered to us, we would still be unable to understand them because we

ourselves constitute part of nature and therefore cannot comprehend nature in its entirety. Although the human mind may be limited in its ability to associate ideas and to visualize and remember details, yet there does not seem to be any indication that our conceptions of natural phenomena are distorted by the inherent peculiarities of our own minds so as to make such phenomena appear paradoxical or incomprehensible. On the contrary, it appears that all natural phenomena, with hardly a single exception, can now be explained or accounted for in a perfectly rational manner, at least in principle if not in detail, on the basis of statistical mechanics and geometrical relationships.

This conclusion may seem contrary to some of the recent versions of the relativity theory as for example the special postulate which states that the velocity of light is independent of the relative velocity of observer and source, but it is only the actual experimental facts and not the theories which must be conformed to. For example, in the Michelson-Morley experiment, which formed the main experimental basis for the special postulate of relativity, the negative result can be completely accounted for if we regard the earth as a stationary system so that the velocity of light in the immediate neighborhood of the earth will be 2.99735×10^{10} cms. per second in any direction relative to the earth. The justification for this will be obvious when it is considered that light-waves consist of undulations in the lines or fields of force of protons and electrons. On the earth's surface these lines or fields of force originate almost entirely in the earth itself so that all optical experiments conducted on the earth will proceed as if the latter were a stationary system. It is different in the depths of interstellar space where the lines or fields of force are contributed by celestial bodies distributed in all directions so that a ray of light travelling in these

regions will have a velocity of 2.99735×10^{10} cms. per second relative to the center of mass of the surrounding universe and not relative to any particular star or planet.

The objection to the special postulate of relativity is not that it is difficult to visualize, but that it is inconsistent and self-contradictory. It is different with Newtonian or classical relativity which is almost universally accepted, but which is continually being confused with special relativity. Neither should special relativity be confused with the Lorentz contraction which consists of an apparent shortening of every moving body in the direction of its motion due to the finite velocity of light, the Lorentz contraction being a purely geometric proposition which does not involve any theory at all.

Another development of the modern relativity theory has been the suggestion that gravitation may be due to a curvature of space. The main argument which was originally advanced in support of this proposition was that gravitation cannot be screened in the same manner as electricity and magnetism. However, the apparent screening of electricity and magnetism is in reality a condition of electrostatic or magnetic polarization of the material of which the screen is composed, whereby the effects of the impressed electric or magnetic forces are neutralized. It further appears that the curved-space theory does not really explain gravitation but is merely a convenient method of expressing the facts in mathematical language.

It appears that gravitation can be accounted for in a perfectly rational manner by assuming that the forces of attraction between protons and electrons are slightly greater than the forces of repulsion between the protons alone and between the electrons alone. For example, every electron in the earth attracts every proton in the

sun, and vice versa. Similarly every proton in the earth repels every proton in the sun and every electron in the earth repels every electron in the sun. Since the electrostatic forces between protons and electrons are enormously greater than the gravitational forces, it would require only an extremely small difference between the combined electrostatic forces of attraction and those of repulsion to account for the observed force of gravitation. Protons and electrons being probably dissimilar in structure as will be explained hereinafter, there seems to be no reason for assuming that these forces of electrostatic attraction and repulsion must be exactly equal.

It has recently been observed that the spectra of nearly all distant nebulae are shifted towards the red, and that the amount of this shift is proportional to their distances from the earth. According to the Doppler principle this would indicate that all distant nebulae are moving away from the earth, and that their velocities of recession are proportional to their distances from the earth. Such a conclusion is, however, so preposterous that it would be better to suspend judgment than to accept it as a fact. Efforts have also been made to account for this "red shift" on the basis of non-Euclidean geometry and curved space, but these are only mathematical schemes for describing the observed facts and are not real explanations thereof.

What the red shift actually consists of is a slight increase of wave-length, amounting to only about one-fifteenth of an octave during 100,000 years. Since a single train of light-waves is never more than a few meters in length, it would require only an extremely small expansion of the wave-train as a whole to produce such an increase of wave-length, and this is evidently due to a slight mutual repulsion between the individual waves.

It has recently been found that X-rays exhibit not only the properties of waves but also the properties of corpuscles, and what is true of X-rays is probably also true for any other kind of light. Since mutual repulsion is a well-known property of corpuscles such as protons and electrons, it is not unlikely that light-waves may also possess this tendency to a slight extent. If we assume that a train of waves consists of a succession of electrical undulations, then the mutual repulsion may be due to the abrupt transitions from flux in one direction to flux in the opposite direction as we pass along the wave train.

The principles of magnetism and electricity no longer involve any insuperable difficulties. For example, magnetism can be completely explained by attributing it to the forces of attraction or repulsion between the peripheral electric currents in the surrounding solenoids and in the magnetic atoms. If the electric currents around the adjacent ends of two magnets flow in the same direction, the magnetic poles will be of opposite sign and will attract each other, whereas if these currents flow in opposite directions, the magnetic poles will be of the same sign and will repel each other. The north and south poles of a magnet bear the relation of mirror images to each other, there being no intrinsic difference between them.

It will be seen from the foregoing that the problem of explaining magnetism resolves itself into the problem of explaining why two electric currents flowing in the same direction attract each other, and when flowing in opposite directions repel each other. The reason for this will be apparent when we take into consideration the fact that all matter in its electrically neutral condition is composed of negative electrons and positive protons, and that when a current is flowing in a wire it is only a few of the elec-

trons in the outermost portions of the atoms which are actually moving. The atomic nuclei and all the protons remain in fixed positions. When there is only a single wire carrying a current and all the surroundings are at rest, then the various forces of attraction and repulsion which act upon the moving electrons will be the same from all sides. This condition of electric symmetry will be destroyed as soon as we bring a second wire carrying another electric current alongside the first wire. Some of the lines of force from the moving electrons in the first wire will then terminate on the moving electrons in the second wire instead of on stationary electrons, but this new condition will exist on only that side where the second wire is located. No matter from what standpoint we view the situation, a wire carrying an electric current is not electrically symmetrical with its surroundings if there is another current flowing in the neighborhood, and it is this unbalanced electrical condition which causes the two wires to be forced towards or from each other.

A very simple explanation can also be furnished for electromagnetic induction. One method by which we can start an electric current flowing or increase the strength thereof is by pushing against the electrons from behind. In order to do this we must of course employ suitable electrical devices, but these do not need to be considered further at the present time. Now, if we exert such a "push" against an electron so as to accelerate its motion, then according to Newton's third law of motion there will be a reaction, equal in magnitude and opposite in direction, upon the electrons of adjacent conductors, which will start induced currents flowing in the opposite direction. On the other hand, if we retard or stop a current by pulling back on the electrons, then there will be a reaction upon the electrons of adjacent conductors so as to cause induced currents to flow in the same direction.

Prior to the twentieth century the internal structures of the individual atoms were generally thought to be unfathomable mysteries and the term "matter" was used to cover a multitude of ignorances. For a while it seemed as if an impassable barrier had been reached at the threshold of the atom, but this was finally surmounted by the discovery of radioactivity. Protons and electrons were then substituted for atoms as the ultimate particles of matter, and the various motions and configurations of these protons and electrons were suggested as possible explanations for the different physical and chemical properties. These explanations have been fairly satisfactory so far as they related to macroscopic physical phenomena, but have been almost total failures with reference to intra-atomic processes. The shortcomings of the various atomic models which have been proposed during the last quarter century are too well known to require reiteration.

It has been suggested by Rene Descartes in the early part of the seventeenth century that the elementary particles of matter may consist of vortex-rings because vortex-motion is peculiarly self-contained and self-sustaining. Waves or undulatory disturbances are transitory and pass by, but the elementary particles of matter are self-sustaining and perpetual. No matter how vigorously the elementary particles of matter are agitated by heat- or light-radiation, they will not lose their specific individual characteristics. This remarkable persistence of individuality can readily be accounted for on the basis of any vortex-theory of atomic structure, but would be difficult to explain on the basis of the newer theories of wave-mechanics.

The same postulates which are necessary to form the basis for any wave-theory of atomic structure will also be sufficient for a vortex-theory. Although it may be convenient to refer to such waves and vortices as forms

of motion in a hypothetical "ether," yet it should be remembered that this does not mean the actual movement of any material substance but only some sort of space-time relationship. In dealing with problems of atomic structure it is not permissible to make unrestricted use of the classical concepts of mechanics and electrodynamics. The flux of which such waves or vortices are composed is probably not entirely identical with ordinary electric or magnetic lines of force because these are merely the geometric resultants of the overlapping fields of protons and electrons and are not tangible self-contained entities. That electrostatic lines of force cannot constitute the ultimate structural material of the universe will be evident from the fact that the force between two charged bodies depends not only on their charges but also on their environment. For example, two bodies having charges of $+100$ and -100 volts respectively will under ordinary conditions attract each other, but if both are placed in a medium which is itself under an absolute potential of $+200$ volts they will repel each other.

Prior to the discovery of the electron the entire atom was thought to consist of a single vortex-structure, and the characteristic properties of the different chemical elements were assumed to be due to different systems of knotting or interlinking of the vortex-filaments. Toward the end of the nineteenth century these primitive ideas had to be abandoned since it became evident that the atom was not a single indivisible entity but consisted of a collection of protons and electrons. The apparent inability of the vortex-theory to account for the two kinds of electricity soon caused it to become discarded altogether, but of all the atomic models which have been proposed since that time there is not a single one which accounts for the permanentness and individuality of the elementary particles of matter as satisfactorily as the vortex-structure. That the atoms cannot consist of

knotted or interlinked vortex-filaments will be evident from the fact that such knotting or interlinking will necessarily bring together adjacent sides with flux in opposite directions which would probably result in mutual repulsion and consequent breaking up of the vortex-filament. It is different with ordinary circular vortex-rings which involve no sudden transition from flux in one direction to flux in the opposite direction. Consequently before the vortex-theory is to be totally re-

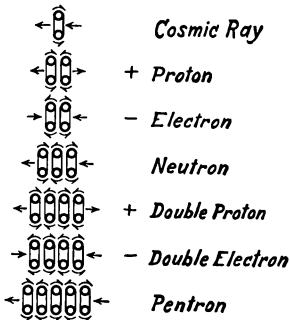


FIG. 1. Groups of electrical vortices as the ultimate building-material of the universe.

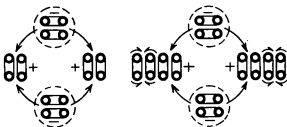


FIG. 2. Hydrogen isotopes of molecular weights 2 and 4 respectively.

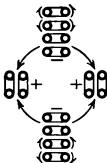


FIG. 3. The helium atom of atomic weight 4.

jected, an attempt should first be made to account for the two kinds of electricity and for the various other phenomena of atomic physics on the basis of structures formed of circular vortex-rings.

For several decades it was thought that protons and electrons were the smallest particles of matter in the universe, but there has recently been discovered by R. A. Millikan a very penetrating kind of radiation known as "cosmic rays." These were first thought to consist

of undulatory disturbances of wave-lengths considerably shorter than X- or gamma-rays, but more recent experiments have shown that they are received intermittently and not continuously so that they must be regarded as particles rather than waves. Since cosmic rays are not deflected by electric or magnetic fields and are more penetrating than any other known kind of radiation, they must consist of particles which are electrically neutral and are smaller than any other known kind of particle. If the foregoing vortex theory is to be adhered to, then the only conclusion which can be reached from these various considerations is that cosmic rays consist of single vortex-rings.

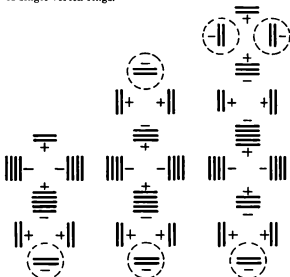


FIG. 4. The lithium, beryllium, and boron atoms of atomic weights 7, 9, and 11 respectively.

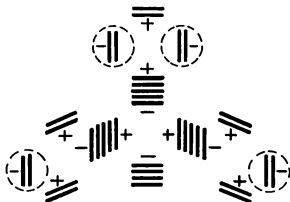


FIG. 5. The carbon atom of atomic weight 12.

Since a single vortex-ring can exist in only one form, it will not account for the two kinds of electricity; but by grouping such rings into pairs there will be produced double vortex-rings in which the adjacent sides flow either inwardly, outwardly, or in opposite directions. The first two of these arrangements are each structurally symmetrical but not similar to each other and probably correspond to protons and electrons respectively, whereas the third arrangement is unsymmetrical and probably unstable on account of mutual repulsion between adjacent sides with flux in opposite directions. Direct experimental evidence of such double vortex structure has been furnished by the recent investigations of parahydrogen and spinning electrons which have shown that protons and electrons are capable of spinning either as entireties or with the two halves rotating in opposite directions.

Electrostatic attraction and repulsion may be due to the formation of larger vortices linking together the indi-

vidual protons and electrons. The outward equatorial flux from the one may be assumed to pass directly over into the inward equatorial flux of the other, and the outward polar flux of the latter back into the inward polar flux of the former so as to form a closed circuit. Since the smaller vortices which constitute the individual protons and electrons must be assumed to be in equilibrium, it necessarily follows that the larger vortices would tend to shrink so as to draw these protons and electrons together. The repulsion between similar charges may then be attributed to the attraction between the latter and their surroundings which will tend to draw them away from each other.

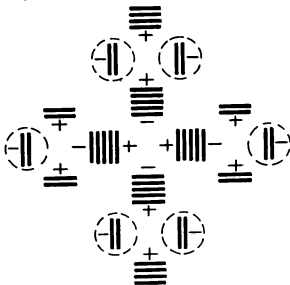


FIG. 6. The oxygen atom of atomic weight 16.

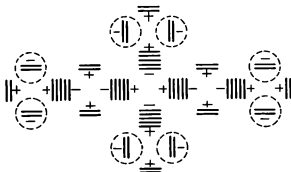


FIG. 7. The neon atom of atomic weight 20.

When protons and electrons are brought into close proximity with each other as in the interiors of the atoms, the usual forces of attraction will change over into forces of repulsion which may be due to the abrupt transitions from flux in one direction to flux in the opposite direction in the regions between closely adjacent sides. On the other hand it appears that the usual repulsion between two protons or between two electrons may be converted at very short distances into forces of attraction because all the flux between adjacent sides will then be in the same direction.

Although double vortex-rings can exist in two different configurations, yet there is only one configuration possible for triple vortex-rings. In a triple vortex-ring if the first and second rings are arranged to constitute an electron, then the second and third will constitute a proton, or *vice versa*. Such a triple configuration should therefore be electrically neutral, should have approximately the mass of one proton, and on account of its small size and electrical neutrality it should have great powers of penetration. These properties seem to

indicate that it may correspond to the recently discovered neutron. As the number of vortex-rings in the series is increased it will be found that every even-numbered group can exist in either of two different configurations which will have a surplus of one positive or one negative charge respectively, whereas every odd-numbered group can exist in only one configuration which will be electrically neutral. The possibility of arranging vortex-rings into compact groups of this sort will also explain the great densities of some of the dwarf stars, some of which have densities thousands of times greater than that of any known substance.

It will be observed from the atomic structures shown in the accompanying diagrams that any group which couples together two hydrogen or helium nuclei contains an odd number of vortex-rings and carries equal and opposite electric charges at its two ends. This is necessarily so because if it would contain an even number of vortex-rings it would have just one surplus proton or electron, the flux of which would have to be divided between the two adjacent hydrogen or helium nuclei, whereas the latter cannot take less than one complete proton or electron each. It appears from the atomic weights of the various elements that such intermediate groups are usually pentrons. The substitution of a neutron for a pentron would produce a lower isotope. This is clearly illustrated by the lithium atom in which the two isotopes of atomic weights 6 and 7 are evidently characterized by the presence of a neutron or a pentron, respectively, between the hydrogen and helium nuclei.

By comparing the accompanying chart with the preceding figures it will be found that there is close correspondence between the number of spectral lines of each element and the number of dissimilar positions in its atomic structure which are occupied by the different electrons. For example, hydrogen has only one spectral

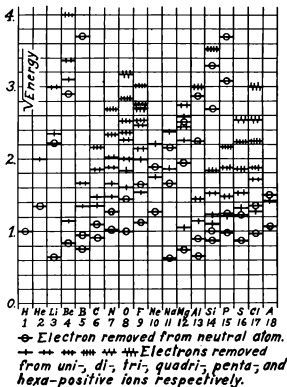


FIG. 8. Atomic spectra. The ordinates represent the square-roots of the energies which are required for displacing the various electrons from the atoms or ions, these energies being proportional to the frequencies of the emitted radiation.

line because the removal of either of the electrons would disrupt the entire molecule. Helium, on the other hand, has two spectral lines because one electron can be removed from each of the double electrons without disrupting the atom. After the first electron is removed, the atom will be positively charged so that the removal of the second electron will require more energy than was necessary for the removal of the first. Lithium shows four spectral lines. This is about what should be expected because an inspection of Fig. 4 will show that the neutral lithium atom has three removable electrons, two of which are on a helium nucleus and occupy similar positions so that they will both produce the same spectral line. Theoretically the lithium atom should produce a total of five spectral lines instead of four, but it may be assumed that the helium nucleus will not lose both of its difficultly removable electrons while the more easily removable single electron remains in place. Similar relationships will be found between the atomic structures and the spectral lines of the heavier elements, but the problem increases so rapidly in complexity that it could not be pursued much further without the use of models.

There is probably no phenomenon of modern physics which has more stubbornly resisted all efforts towards explanation than the photoelectric effect. Whenever any substance, either solid, liquid, or gaseous, is illuminated with light of sufficiently short wave-length, there occurs immediately an emission of negative electrons. For every substance there is a definite upper limit to the wave-lengths which will cause this emission, radiation with wave-lengths longer than such critical values producing no effect whatever, regardless of the intensity of the light. The maximum wave-length at which photoelectric emission will occur is greater for electro-positive

than for electro-negative substances. For caesium and other alkali metals it lies in the visible regions of the spectrum whereas for non-metals it lies far in the ultra-violet.

It has been found that the maximum velocity with which photo-electrons are ejected depends only on the wave-length or frequency of the light and is entirely independent of its intensity. The shorter the wave-length of the light, the greater is the maximum velocity of ejection. Increasing the intensity of the light will result in the emission of greater numbers of electrons but will not increase their velocities.

This behavior seems impossible to explain as long as we consider the electrons as merely point-charges movable in orbits about the atoms, but will offer no special difficulties if we regard them as specific structural units occupying definite positions in the frameworks of the atoms. Instead of the different quantum-orbits of the Bohr-atom we will then have different quantum-positions which the various electrons may occupy. In each of these positions the surrounding electric fields will be of definite intensity, depending only on the structure and constitution of the remainder of the atom. The electron which occupies such a position should therefore have a definite frequency of resonant vibration and as soon as its amplitude becomes sufficient to carry it beyond the field of atomic attraction it should dive out into space as a photo-electron. Those electrons which occupy positions of greater electric intensity should have greater frequencies of resonant vibration, should require greater amplitudes to carry them beyond the region of atomic attraction, and should dive out into space with greater velocities than those which occupy positions of lesser intensity, this being exactly what has been observed experimentally.

The emission of photo-electrons takes place as soon as the material is struck by the light. Even with radiation

as feeble as that from an ordinary candle three meters away the lag is less than a millionth of a second, whereas it would have required several hours for the ejected electrons to intercept enough energy from the impinging radiation to produce the velocities with which they left the atoms. It has therefore been suggested that the light-radiation may carry its energy in definite bundles or quanta and that an atom or electron absorbs either the whole of such a quantum or none at all, but such a radical departure from the classical electromagnetic theory is thought to be unnecessary. The promptness with which photo-electrons are emitted from an illuminated surface may be due to their wide range of amplitudes. Although the majority of them will have amplitudes not much different from the average and much too small to cause their ejection, yet at each instant there may be a few of them with amplitudes much greater than the average and sufficient to carry them permanently beyond the fields of atomic attraction.

Recent experiments have shown that streams of high-velocity electrons after encountering or traversing certain solid substances will produce interference bands on photographic plates. It has therefore been concluded that such electrons must be accompanied by wave-like disturbances, and an inspection of the double-vortex electron-structure in Fig. 1 will show that any line drawn through such an electron and following along the lines of flux will assume the form of a sinuous curve. It is therefore readily conceivable that when such an electron encounters or traverses a material body it will set up an undulatory disturbance in the latter and at the same time lose a portion of its own velocity. This undulatory disturbance should have a frequency depending only on the velocity and dimensions of the electron, and for an

electron travelling at the velocity of light it should have the same wave-length as the above-mentioned sinuous curve. It has been found by actual measurements of the interference bands produced by such undulatory disturbances that the wave-lengths thereof are inversely proportional to the electron-velocities, and for electrons travelling at the velocity of light the corresponding wave-length should be about 0.023×10^{-8} cm. This is somewhat less than one-sixtieth of the diameter of the carbon atom. An inspection of Fig. 5 will show that the corresponding wave-length as measured directly from this figure is about one-twentieth of the diameter of the atom, but this discrepancy is probably due to the fact that the multiple-vortex groups in this figure have been crowded together as close as possible in order to conserve space, and in reality are probably spaced from one another several times the distances indicated.

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CHAPTER III

THE UNIQUENESS OF LIFE PROCESSES

"What surpasses our understanding is not the simple anatomical or physiological facts considered in isolation—the excitation of a particular nerve, the contraction of a particular muscle, the secretion of a particular gland—but their coordination in the interests of the organism."

Sul Concetto della Vita by A. STEFANI (1906).

The various forms of life which are encountered in nature exhibit such a variety of appearances and such a profusion of details that it is often difficult to gain a clear conception of life-processes in their entirety and to distinguish what is fundamental and indispensable from what is superficial and unessential.

Life is usually recognized by specific bodily form, spontaneous mobility, and responsiveness to stimuli, but these characteristics can all be closely imitated artificially by means of models and in the lowest forms of life are often entirely absent, so that they must be regarded as secondary features which have developed in the course of evolution and not as primary or distinguishing characteristics of life itself.

Every living organism is, however, unique in that it constitutes an autonomous self-contained entity which is capable, under favorable conditions, of growing and producing others like itself. No artificial device has ever been produced which is capable of reproducing itself. Although growth and reproduction, in their broadest aspect, amount to nothing more than self-duplication or self-perpetuation, yet they are fundamentally different from any of the other processes known to science.

Biological growth does not proceed in the same manner as the growth of crystals because extensive irreversible

chemical transformations always take place during metabolism whereas the growth of crystals from saturated solutions is usually reversible and without chemical change. Biological growth takes place by intussusception whereas crystal growth takes place by accretion. Biological growth does not require saturated solutions such as are necessary for the growth of crystals. Another difference is in the final result produced, for whereas biological growth produces structures which are generally of rounded contour and internally heterogeneous, yet crystal growth produces structures which are generally of angular contour and internally homogeneous.

Biological reproduction, as illustrated by even the simplest cases of cell-division, involves more than mere dispersion or subdivision because the progeny of living organisms retain, either actually or potentially, not only the same chemical compositions but also the same anatomical organizations as their parents. Neither can reproduction be considered analogous to chemical dissociation because the progeny of living organisms inherit all the anatomical features of their parents, whereas the particles which result from dissociation do not carry with them any complete replicas of the molecules from which they were derived.

The ultimate cause of life, whether it be a certain substance or a specific detail of physical structure, must be the same for all living organisms because living matter is always composed of substantially the same protoplasmic material and always passes through the same cycles of growth and reproduction regardless of its rank in the plant or animal kingdom. The morphological differences which ordinarily distinguish one species from another disappear as we go down the scale of plant or animal life. Since there are innumerable species of bacteria which exhibit no internal heterogeneity whatever, even under the most powerful magnification, it appears that

the ultimate units of living matter must exist on a scale smaller than the limit of microscopic vision, and that the ultimate cause of life must be looked for in the realm of chemistry rather than in the realm of physics.

That the fundamental life processes must be due, either wholly or partly, to specific chemical structures is generally admitted, but there is a prevailing opinion that the chemical configurations which are necessary for this purpose must be extremely complex. The failure of all previous efforts to devise some type of chemical structure which would be capable of duplicating or perpetuating itself does not prove, however, that the solution of the problem must lie in the direction of extreme complexity. The complex chemical structures which make up the tissues of the higher plants and animals have developed gradually during the course of evolution, and the fact that such structures are indispensable for the proper physiological functioning of the organisms in which they now occur does not prove that they were also the original cause of the incipient life processes in the most primitive forms of living matter which first appeared on this earth.

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CHAPTER IV

PROTOPLASMIC CHEMISTRY

"The morphologist, on the one hand, strives to elucidate the structures of protoplasm down to its finest details; the biochemist, on the other hand, with his apparently ruder yet still more searching methods, seeks to determine the chemical functions of the same protoplasm; broadly speaking, they are only dealing with two different sides of the same thing."

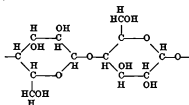
Die chemische Organization der Zelle by
W. HORMEISTER (1901).

Those substances which are actively engaged in the carrying out of life-processes have been designated collectively as "protoplasm" or "living matter." They form a complex mixture including plastic chemical fabrics and fibrous networks, as well as substances in the dispersed or molecular state. In some of the bacteria this mixture forms a homogeneous mass, but in most other cells it is separated into two or three phases, the most prominent of which are the nucleoplasm and the cytoplasm.

It was formerly thought that life-processes were carried out primarily by the cell-wall and that the protoplasm inside was nothing but waste-material. The cell-wall, if present, may include a thin plasma-membrane forming the exterior surface of the cytoplasm, and an outer or true-membrane. As will be evident from its chemical constitution, the cell-wall must be regarded as a secretion-product or a transformation-product of the cytoplasm. The plasma-membrane is usually so thin that its very existence is sometimes doubtful, but when present it is probably of protein-lipoid constitution similar to the plastin or linin network inside. The true-membrane, if present, and intercellular substances generally,

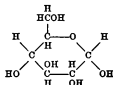
consist of insoluble nitrogenous materials such as keratin or chitin in the case of animal-cells, and of cellulose, pentosans, pectins, and other organic and inorganic materials in the case of plant-cells.

Cellulose forms the principal structural material of all higher plants. In young plants the outer cell-walls consist entirely of cellulose, but as the plant grows older the cellulose becomes impregnated with lignin, cutin, mucilage, and similar materials. Pure cellulose, which is obtained principally from cotton, is a lactone-ring polymerization product having the following chemical structure:

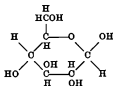


Pectins, starches, mucilages, and gums probably also consist largely of lactone-ring condensation products, but their chemical structures have not yet been determined with certainty.

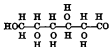
Glucose is probably the first sugar that is synthesized from carbon dioxide and water. In the solid state, and for a short time after solution in water, it exists as a lactone ring with either of the two following configurations:



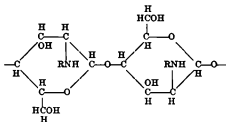
α -Glucose

 β -Glucose

While in solution it gradually changes by tautomerism into the aldehyde form:



Chitin is a nitrogeous material which forms the exoskeletons of many invertebrates. Upon hydrolysis it is converted quantitatively into glucosamine and acetic acid. It has the following chemical structure:



Toward the end of the nineteenth century it gradually became known that most cells are not hollow but solid bodies and that many of the animal-cells do not have any distinct cell-wall but are merely naked masses of cytoplasm containing a nucleus. More recently it has also been shown that in both plant- and animal-cells the nucleus is the center of constructive metabolism and the

seat of heredity, so that interest gradually shifted from the cell-wall to the interior.

During cell-division the nuclear membrane disappears and the nuclear fluids mix with the cytoplasmic fluids so that small quantities of nuclear materials may normally occur as cytoplasmic inclusions. A complete separation of nuclear from cytoplasmic materials is possible only in exceptional cases. The spermatozoa of fishes are peculiarly suitable for this purpose because the cytoplasmic tails can readily be separated from the nucleoplasmic heads by solution in dilute acetic acid. The two portions can then be separately analyzed. In this manner it has been found that the nucleoplasm contains insoluble basic proteins whereas the cytoplasm contains the more soluble proteins and the fatty and lipid materials.

With regard to their staining-reactions, the cell-contents may be divided into oxyphilic, (taking acidic stains such as eosin), and basophilic, (taking basic stains such as methylene blue). The plastin or linin network of the cytoplasm and nucleus is predominantly oxyphilic, but it should be remembered that all proteins are amphoterie and will take both acid and basic stains in varying proportions. In contrast to the above, the chromatin material of the nucleus, the nucleolus, and the chondriosomes and granules of the cytoplasm are basophilic, which may be due to the phosphoric acid radicles of their nucleoproteids.

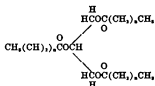
The cytoplasm may have the appearance of either a watery colloidal solution with varying degrees of viscosity, or of a fibrillar or alveolar network with or without vacuoles, granules, or other inclusions. Although it changes greatly in appearance and physical properties during different periods of development, yet it exhibits such unmistakable individualism in its behavior that its

ultimate structural units must be assumed to possess some specific chemical configuration which is characteristic of the species. These cytoplasmic structural units are rod-like or thread-like in form and under high magnification can be seen in actively streaming protoplasm. They are probably of protein constitution with fat or lipoid radicle clinging to them. The variations in appearance and physical properties of the cytoplasm may be attributed to varying degrees of polymerization or dissociation of these structural units. Cytoplasmic fluids are normally slightly alkaline and contain their dissolved proteins in the form of sodium or potassium proteinates. Precipitation of the proteins occurs immediately upon the addition of acid but not upon the addition of alkali.

The union between the prosthetic fatty or lipoid groups and the protein chemical structures is probably of a chemical nature so as to form monomolecular layers because such protein-lipoid combinations will not give any of the usual tests for fats with osmic acid or Sudan III, and the fatty or lipoid materials can be removed therefrom only with boiling alcohol. It has also been suggested that the fatty or lipoid materials may be held to the proteins by adsorption, but it is doubtful if adsorption, without definite chemical union, can take place on anything as pliable and changeable as the protein chemical fabric.

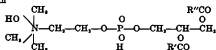
Fats are triple esters of glycerol and fatty acids. They are insoluble in water but soluble in boiling alcohol and in ether. Those fats which contain relatively large proportions of stearic or palmitic esters are hard and solid at ordinary temperatures, whereas those which contain relatively large proportions of butyric or oleic esters are pasty or liquid. It is not uncommon to find the radicles of different fatty acids in the same fat molecule so as to form mixed esters. For example, butter fat is a mixed ester of stearic and butyric acids. The hydro-

carbon chains of the fatty acids sometimes contain one or more double bonds as in the case of oleic acid, but are hardly ever branched. Nearly all natural fats contain only those fatty acids which have an even number of carbon atoms in the molecule. A typical fat molecule may appear somewhat as follows:

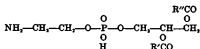


Lipoids or phosphatides are those fatty substances which swell or form colloidal solutions in water and which contain both nitrogen and phosphorus. Their best-known representatives are the following:

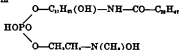
Lecithin



Kephalin

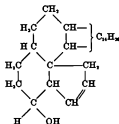


Sphingomyelin



Another fatty substance which occurs in all animal tissues is

Cholesterol



The cell-nucleus appears as a transparent and homogeneous hydrosol during the resting stage, but as soon as cell-division commences it changes over into a hydrogel. Two phases then appear, one of which is formed of the chromatin material consisting principally of water-soluble nucleoproteids and the other of which is formed of the linin network consisting of insoluble proteins. The latter will not dissolve in either water or pepsin-hydrochloric acid which serves to distinguish the nuclear from the cytoplasmic proteins.

The nucleoproteids are compounds of basic proteins such as protamines or histones with nucleotides. The latter are formed of a pentose (d-ribose) to which is joined a purine or pyrimidine group and also a phosphoric acid radicle. Nucleoproteids are acid in reaction and dissolve in water or alkali but not in alcohol or ether. They are precipitated from their water solutions by acid, and with an excess of acid can be decomposed into protein and nucleic acid.

The nucleoproteids are probably formed during cell-division. They have been found to be of general occurrence in cells which have the power of growing and dividing, including even the bacteria which show no visible separation of nucleoplasm from cytoplasm. On the other hand, they do not occur in the erythrocytes of

mammals which have no nuclei and are not able to grow or divide, although they do occur in the nucleated erythrocytes of birds and reptiles.

The proteins are solid or colloidal substances which are thought to be primarily responsible for the carrying out of life-processes. The proteins of plants occur mainly as accumulations of non-specific reserve-material whereas the animal-proteins occur almost entirely as chemically specific cell-structures or tissue-materials. Proteins are usually classified according to their solubilities or digestibilities, and range all the way from the albumins which are soluble in water and readily digestible, to the plastin-(linin) and keratin-materials which are insoluble in water, alcohol, or dilute acid or alkali and are undigestible by pepsin or trypsin. All proteins contain carbon, hydrogen, nitrogen, and oxygen in somewhat variable proportions. Cytoplasmic proteins also contain hydrosulphide or disulphide radicles whereas nuclear proteins contain phosphoric acid radicles.

All proteins decompose hydrolytically upon prolonged boiling with hydrochloric or sulphuric acid or with alkalies, upon treatment with superheated steam, or upon treatment with certain enzymes such as pepsin or trypsin, and yield as their principal cleavage-products a mixture of amino acids or their anhydrides, the structural formulas of the more important ones being as follows:

Amino acids with one nitrogen atom:

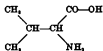
Glycine



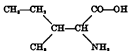
Alanine



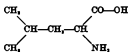
Valine



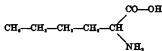
Isoleucine



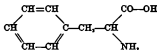
Leucine



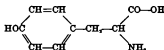
Caprine



Phenylalanine

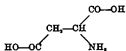


Tyrosine

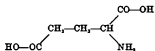


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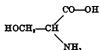
Aspartic acid



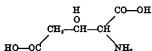
Glutamic acid



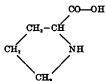
Serine



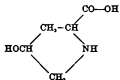
Oxyglutamic acid



Proline

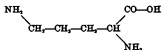


Oxyproline

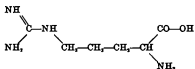


Amino acids with several nitrogen atoms:

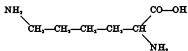
Ornithine



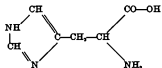
Arginine



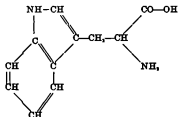
Lysine



Histidine



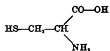
Tryptophane



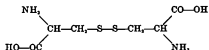
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Thio-amino acids:

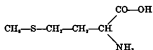
Cysteine



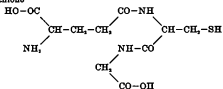
Cystine



Methionine

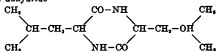


Glutathione

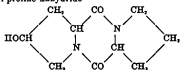


Anhydrides:

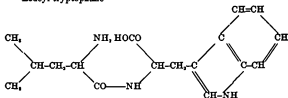
Leucine anhydride



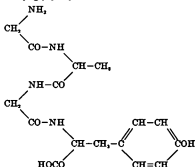
Oxyprolyl-proline anhydride



Leucyl-tryptophane



Glycyl-alanyl-glycyl-Tyrosine



The accompanying table gives the percentage yields of the various amino acids from certain proteins, but these values should be interpreted cautiously because the specific chemical structures of some of these amino acids may have resulted from degradation processes or may have been formed during hydrolysis. For example, the guanidine group of arginine and the ring-structures of proline, oxyproline, histidine, and tryptophane cannot be fitted into the arrangements suggested in the succeeding chapters but are probably degradation- or waste-products which have not yet been completely eliminated.

There is, in fact, but little justification for employing the molecular concept at all in our consideration of pro-

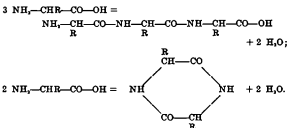
APPROXIMATE PERCENTAGE YIELD OF AMINO ACIDS FROM PROTEINS

	Egg Albumin	Cn- sein	Edes- tin	Fi- brin	Gela- tin	Glia- din	Hemo- globin
Glycine	0.0	0.5	3.8	3.0	26.0	0.02	0.0
Alanine	8.1	1.5	3.6	3.6	8.7	2.0	4.2
Valine	2.5	7.0	6.2	1.0		0.2	
Isoleucine		1.4				0.2	
	11.0		21.0	15.0	7.1	5.6	30.0
Leucine		7.9					
Phenylalanine ..	5.1	3.9	3.1	2.5	1.4	2.4	4.2
Tyrosine	1.8	5.0	2.1	3.5	0.01	1.2	1.3
Aspartic acid	2.2	1.4	4.5	2.0	3.4	0.58	4.4
Glutamic acid	9.1	15.8	19.0	10.0	5.8	37.0	1.7
Arginine	4.9	4.5	15.0	4.7	8.2	3.2	5.4
Lysine	3.8	6.0	2.0	11.0	5.9	0.0	4.3
Serine	0.0	0.4	0.3	0.8	0.4	0.13	0.6
Cystine	0.3	0.02	1.0	1.2		0.45	0.3
Proline	3.6	7.0	4.1	3.6	9.5	7.1	2.3
Oxyproline		0.2	2.0		14.0		1.0
Histidine	1.2	3.0	2.0	6.4	0.9	0.61	11.0
Tryptophane	+	1.5	0.4	1.3		+	+

teins. The molecular theory was introduced for the explanation of the definite and simple proportions in which certain substances react, but the experiments upon which the molecular theory were based did not include experiments with proteins, the combining proportions of which are neither definite nor simple. Those proteins which are soluble in water may consist, not of particles, but of fibrous networks as is evidenced by the opalescence and stringyness of their solutions and by many of their other physical and chemical properties, whereas those which required special reagents to dissolve them, as for example the protamines which require dilute sulphuric acid for their liberation, were probably altered during the process so that they no longer possess the same chemical structures which they had in the living cells. The vulner-

ability of proteins to even the most gentle chemical treatment is well illustrated by the treatment of hair for a short time with dilute hot sodium carbonate solution, which will reduce the cystine yield from about three per cent to almost nothing.

By suitable chemical treatment the above-mentioned amino acids can be condensed, with the elimination of water, to form either chain-structures known as polypeptides or ring-structures known as dioxypiperazines:



Numerous methods for preparing such condensation products have been devised by Emil Fischer and his collaborators in Germany, and molecules containing as many as nineteen amino groups have been prepared.

There is an abundance of evidence that the peptide linking —CO—NH— occurs in the protein materials of all living cells. For example, the same pink or violet color, (the biuret reaction), which is produced from this linking in any of the higher polypeptides by the addition of an excess of sodium hydroxide and a trace of copper sulphate is also produced upon the addition of these reagents to proteins. But what is even more convincing is the fact that numerous polypeptides, dioxypiperazines, and combinations of the two have been found among the hydrolytic decomposition products of

proteins. That the amino acid groups in proteins are connected by means of peptide linkings is also evidenced by the fact that all proteins which have not been treated with mineral acids or alkalies form neutral solutions, so that the number of unoccupied carboxyl groups must be about equal to the number of unoccupied amino groups. The fact that only a small fraction (usually less than ten percent) of the total protein nitrogen can be separated as free amino nitrogen shows that most of the amino groups of the original amino acid radicles must have become modified or occupied in some manner at the time when these amino acids were being assimilated, and it is inconceivable how the removal of exactly equal numbers of amino and carboxyl groups from the field of action could be accomplished in any other manner than by the formation of peptide linkings.

From considerations such as these the conclusion has generally been reached that the protoplasmic materials of living cells grow by the formation of peptide linkings with amino acid molecules so as to produce either the chain-structures of polypeptides or the ring-structures of dioxypiperazines. It was formerly thought that the structures thus produced were entirely of polypeptide nature, but more recent investigations have shown that dioxypiperazines are always present among the hydrolytic cleavage products of proteins, even under conditions which would render their synthetic formation from the initially produced polypeptides improbable. However, the chemical structures of the solid or colloidal protoplasmic materials which have been subjected to hydrolysis may not be identical with the molecular structures of synthetically prepared polypeptides, even though they may both contain peptide linkings, and with our present scanty knowledge of protein structure we would not be justified in assuming, without further experimental evidence, that this difference in chemical structure between proteins and polypeptides would not

be sufficient to explain the formation of dioxypiperazines from the former more readily than from the latter. That dioxypiperazines are not normal constituents of living matter is also evidenced by the fact that neither pepsin, trypsin, nor erepsin will split the dioxypiperazine ring.

But regardless of whether or not the dioxypiperazine ring is normally present in protoplasmic materials, it appears from biological considerations that neither the simple polypeptide structures nor the unaltered dioxypiperazine rings are adequate to explain life-processes. Neither of these structures shows any tendency to grow spontaneously by assimilation of amino acids from dilute solutions of food materials, nor to divide spontaneously into daughter-structures which possess or spontaneously acquire the specific structural organizations of their parents. The self-preserving, self-controlling, and self-directing ability of living matter in all its forms and activities is too pronounced to escape attention, and cannot be explained by any fortuitous juxtaposition of molecules. The determination and persistence with which living organisms will pursue and devour every bit of food material within reach and invade the entire earth's surface with their progeny shows that they must possess within the chemical structures of their tissues some contrivance which is definitely superior to ordinary chemical forces and which can function in a manner unknown to chemical science. What is needed for this purpose is not some new form of molecule but some new type of chemical structure; not some new arrangement, but some new principle.

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CHAPTER V

SPIRAZINES, THE CAUSE OF LIFE

"We must therefore ascribe to living cells, beyond the molecular structure of the organic compounds that they contain, still another structure of different type of complication; and it is this which we call by the name organization."

Elementarorganismen by E. BRÜCKE, (1861).

Growth and reproduction being the two indispensable processes without which life is inconceivable, the chemical structure of living matter from which such life-processes originate must be of such a nature that it will, under constant environmental conditions, and without human intervention, perpetuate or duplicate itself spontaneously to an unlimited extent. Nothing more than this would be necessary to constitute living matter, and nothing less would suffice.

One of the most remarkable characteristics of living organisms is that all the necessary physiological functions can take place while growth is in progress. In this respect living organisms differ from artificial contrivances which usually cannot perform their intended functions while they are in the process of construction. In multicellular as well as in unicellular organisms, physical behavior seems ordinarily to bear no direct relationship to the chemical processes of assimilation. This peculiar independence of growth and behavior can be explained only on the theory that the essential structural characteristics of living matter are not altered by the addition of amino acid radicles thereto.

If the protoplasmic structures of living cells were built up of discrete molecules of utmost complexity as is generally supposed, then it would be impossible to ex-

plain the process of growth which in living organisms takes place continuously and spontaneously by the assimilation of one amino acid radicle after another. However, there is no experimental evidence that the protoplasmic structures of living cells are built up of discrete molecules, or that such structures are of utmost chemical complexity. In regard to their supposed molecular constitution, it might be stated that most proteins, and especially those which form the nuclear or actively growing portions of living cells, require special chemical treatment to bring them into solution; whereas those which will dissolve in water, as for example the albumins, are probably no longer integral portions of the living cell-structures but may consist of free colloidal bodies which grew outwardly from the nuclear material and then became detached. In regard to their supposed chemical complexity, a distinction should be made between two-dimensional and three-dimensional complexity. Although it seems impossible to explain growth and heredity if we assume that the smallest units of living matter possess three-dimensional complexity, yet it seems quite easy to explain these processes if we assume that such units possess only two-dimensional complexity and that the third dimension is built up by mere superposition of layers containing the same chemical structures.

Of the various geometric forms which chemical structures might exhibit, the helical spiral appears to be about the only one which possesses characteristics similar to those mentioned above, and it appears that the helical spiral is also the only configuration, besides rings and chains, which the polypeptide molecule can be made to assume. The readiness with which dioxypiperazine rings are formed from dipeptides, and the difficulty of splitting such rings, seems to indicate that the valencies of the successive carbon and nitrogen atoms are so arranged and constituted as to give them a natural tendency to

form six-atom rings; and if dipeptides tend to form six-atom rings, then polypeptides would tend to form spirals with six-atom convolutions, which will be designated hereinafter as "spirazines."

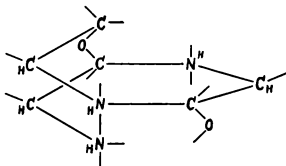


FIG. 9. Neo-form of spirazine.

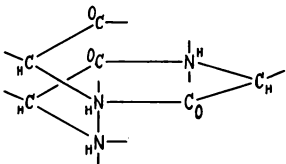


FIG. 10. Carbinol-form of spirazine.

It will be observed that one of the valencies of the alpha carbon atoms in these amino acids is always occu-

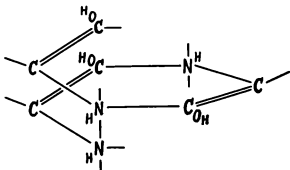


FIG. 11. Enol-form of spirazine.

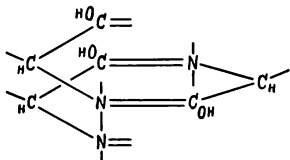


FIG. 12. Imidol-form of spirazine.

pied by hydrogen. Chemically it would be possible to attach more complex groups in this position, but it will be found upon experimentation with atomic models that the presence of more complex groups would render the spiral structure impossible.

The two ends of such a spirazine will be different in that one end will be formed of an acid carboxyl group

whereas the other end will be formed of a basic amino group. When the dissimilarity of chemical structure at the two ends is taken into consideration, it seems highly improbable that the ability to grow by assimilation of amino acid molecules could be possessed by both ends alike, and the fact that the physiological effects of different substances when injected into the blood stream are due almost entirely to the positive cations seems to indicate that assimilation in animal-cells takes place at the carboxyl ends only. The successive nitrogen atoms along the side of a spirazine will increase the basicity of the terminal nitrogen atom, just like the two nitrogen atoms in diazo compounds increase the basicity of each other. Similarly the carbonyl groups along each side of the spirazine will increase the acidity of the terminal carbonyl group. These conditions, in cooperation with certain electric potentials which may result from unequal diffusion of positive and negative ions, may account for the remarkable ability of living matter or its enzymes to digest all sorts of complex food materials and to appropriate the resulting substances spontaneously and continuously for the building up of its own structures.

If the successive nitrogen atoms in a spirazine are joined to one another by means of their fourth and fifth valencies in the manner shown, which seems to be entirely possible by reason of the fact that these valencies in amino compounds are always of opposite sign, then it appears that at least some of the nitrogen atoms in proteins are pentavalent and should therefore be incapable of forming hydrochlorides in stoichiometric proportions as in the case of polypeptides. This is in complete agreement with experimental facts, for it has been found that the amounts of hydrogen chloride gas which are taken up by proteins are much smaller than the amounts which

they should take up if they were of ordinary polypeptide structure.

On the other hand, the amount of acid which a protein is capable of neutralizing is always much greater than the amount which could be taken up by the terminal amino groups at the free positive ends of the polypeptide chains, which never contain more than about ten percent of the total protein nitrogen. Similarly the amount of base which a protein is capable of neutralizing is always much greater than the amount which could be taken up by the terminal carboxyl groups, assuming these to be about equal in number to the terminal amino groups. It must therefore be concluded that the ability of proteins to neutralize acids and bases is due not only to the terminal amino and carboxyl groups, but also, in a large measure, to the peptide groups -CO-NH- along the sides of the spirazines.

The fact that a spirazine possesses a definite direction of twist will also account for the optical activity which is always exhibited by substances obtained from living organisms, and also for the partiality which is usually shown by living organisms towards one optical isomer over the other. In biochemical processes chirality is the rule rather than the exception, and can be accounted for only on the basis of an inherently twisted structure such as the spirazines possess.

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CHAPTER VI

LIVING MATTER

"In the waters of the ancient world, and at the present time, very small masses of mucilaginous (colloidal) matter were collected. Under the influence of light, certain elements, caloric and electric, entered these little bodies. These corpuscles became capable of taking in and exhaling gases; vital movements began, and thus an elemental plant or animal sprang into existence. . . . Nature is thus always creating."

JEAN LAMARCK, 1744-1829.

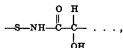
"The synthetic act by which the organism maintains itself is at the bottom of the same nature as that by which it repairs itself after undergoing a mutilation, or by which it multiplies and reproduces itself. Organic synthesis, generation, regeneration, reintegration, the healing of a wound, are but different aspects of a single phenomenon."

Leçons sur les phénomènes de la vie by C. BERNARD, (1878).

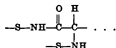
It seems to be the general opinion at the present time that the synthetic production of living matter can be hoped for only in the distant future, but it appears not only from the comparatively simple form of the spirazine structure but also from the recent experimental work of A. L. Herrera in Mexico that a more optimistic attitude would be justifiable. For example, there are many ways in which unsaturated or ketonic acids could be formed spontaneously from the simpler carbon compounds such as formaldehyde or acetylene, and the combination of these with ammonia will produce amino acids. There remains then only the problem of bringing about the condensation of these amino acids into polypeptides and the transformation of the latter into spirazines, both of which processes should be capable of taking place spontaneously under suitable conditions.

The recent experiments of A. L. Herrera have shown that microscopic cellular bodies having practically all the characteristic forms and activities of natural unicellular organisms can be produced artificially by the action of formaldehyde on ammonium sulphide in the presence of nitric acid fumes, and also by the action of formaldehyde on ammonium thiocyanate. These synthetic cellular bodies have exhibited a remarkably lifelike appearance and have been observed to contain certain details bearing a close resemblance to chromosomes, asters, and spindles. There has also been some evidence of the photosynthesis of starch from carbon dioxide and water.

There is still much uncertainty as to the exact nature of the chemical reactions, but it appears that the formation of polypeptide structures from these reagents would be entirely possible because of the ability of aldehydes to polymerize into carbohydrates and to combine with nitrogenous substances to form aldehyde-ammonias. For example, the ammonium sulphide or the ammonium thiocyanate, each of which contains the group $-S-NH_4$, may have combined with atmospheric carbon dioxide or with formaldehyde or its polymerization products in the presence of nitric acid fumes or atmospheric oxygen to form structures of the type:



and the latter may then have condensed with some more ammonium sulphide or thiocyanate molecules to form structures of the type:



If either of the sulphur atoms in the above structure then dissociates from its adjacent nitrogen atom, the latter will again be free to combine with some more carbon dioxide or aldehyde, and in this manner the process may repeat itself any number of times so as to form polypeptide chains of any length. Evidently there may be something more involved here than just ordinary colloidal condensations, and if synthetic life has not already been produced then its production may be expected any time.

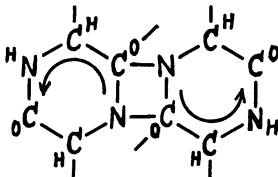


FIG. 13. A double linking between two spirazines.

The evolutionary development of more complex organisms can be accounted for by assuming that some of the spirazines are capable, under certain conditions, of folding over upon themselves so as to enlarge the pattern. The folded-over portions will remain clinging to the original portions because of the affinity of the basic amino groups of one of these portions for the acid carbonyl groups of the adjacent portion. The hydrogen from the amino groups will combine with the oxygen from the carbonyl groups to form water, and the nitro-

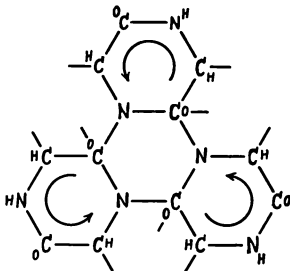


FIG. 14. A spirazine triplet, formed by the repeated folding over of a single spirazine.

gen and carbon atoms of the adjacent spirazines will then be left connected directly to each other. It might appear from diagrammatic illustrations on paper that when a spirazine folds over upon itself, the amino and carbonyl groups of the folded-over portion would come directly opposite the carbonyl and amino groups, respectively, of the original portion, so that they would be likely to combine chemically as suggested in Fig. 13. It is doubtful, however, whether such a double union can occur in nature. The adjacent portions of the convolutions of two spirazines with the same direction of twist will always slope in opposite directions, which would render it difficult to bring the amino and carbonyl

groups into positions directly opposite each other along two parallel lines without considerable distortion of the spirazines themselves. It seems more likely that the folded-over portion will join the original portion along only a single line, so that repetitions of this process will produce the spirazine triplet shown in Fig. 14, and eventually the configuration of polygonal compartments shown in Fig. 15. The broken ends of the spirazines can then continue to grow longitudinally in the same manner as before, and if the entire structure divides transversely into two halves each daughter portion will retain a complete replica of the enlarged pattern. Every time when such a folding-over occurs the structure will become more complex, and any feature which is thus added to the pattern will be perpetuated throughout all future generations.

It is an interesting fact that proteins from the most diverse sources will all rotate the plane of polarization of light to the left. The fact that animal-proteins have the same direction of rotation as vegetable-proteins might be accounted for on the theory that since animals either feed upon plants directly or upon other animals which do feed upon plants, it might be expected that the structural materials of plant- and animal-tissues would exhibit some features in common. It is not so easy, however, to explain why all plant proteins rotate the plane of polarization to the left, unless we are willing to admit that all the present species of plants have descended, not only from a single ancestral species, but also from a single spirazine. If there would be only a few of these optically active proteins then their uniform optical properties might be attributed to coincidence; but since the number of proteins whose optical properties have been determined runs into hundreds, the possibility of it being due to coincidence must be ruled out.

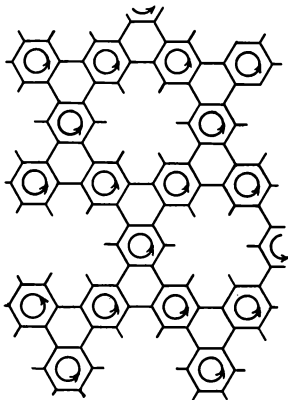


FIG. 15. A cross-section of protoplasmic structure. The large open spaces are probably filled with prosthetic groups such as fat or lipid radicles.

The purpose of sulphur and phosphorus in living matter must be left as an open question. It has been suggested that sulphur may play some part in oxidation and reduction reactions by passing alternately into the disulphide and hydrosulphide forms. It has also been thought to assist in the process of cell-division. Protoplasmic phosphorus has been suspected of being a catalytic agent for assisting the assimilation of amino acid molecules, just like sulphuric acid acts catalytically to facilitate the combination of alcohols with acids. All known forms of living matter contain both sulphide and phosphate radicles, and it has been found that sulphur and phosphorus compounds are indispensable for the nourishment of all known forms of life. It has therefore been generally concluded that sulphur and phosphorus are necessary for any form of life, but such a conclusion does not necessarily follow.

Living matter is so constituted that it will retain only certain kinds of substances. For example, it will retain formaldehyde, cyanides, and heavy metals, but will be poisoned thereby; it will retain amino acids for structural material; it will retain fats and lipoids as prosthetic groups; it will retain carbohydrates for use as fuel; and finally it may retain sulphur and phosphorus compounds for no other reason than merely because they are so constituted chemically that they will permanently attach themselves to certain parts of the protoplasmic structures. It must not be assumed that every structural detail which is found in living matter has been placed there for a purpose. Living organisms must accept their environment as they find it, and in order to survive they must tolerate what they cannot escape. The possibility that the presence of sulphur and phosphorus combinations in living matter may originally have been purely adventitious is not contradicted by the fact that sulphur and phosphorus compounds are in-

dispensable for the nourishment of all known forms of life. Since the original spirazines which must have constituted the most primitive forms of living matter were thousands of times smaller than the smallest known bacteria, there must have been many intermediate stages of evolutionary development, and the persistent presence of sulphide and phosphate groups in living matter, although at first merely tolerated, may later have induced adaptations rendering such groups indispensable.

On the other hand the experiments of A. L. Herrera seem to indicate that carbon compounds of sulphur and nitrogen may have been primarily responsible for the organization of non-living materials into primitive cell-like bodies capable of growth and multiplication, but not possessing any specific germinal pattern that is characteristic of the species. Such primitive cell-like bodies may have constituted an intermediate stage between non-living and living matter, for it is readily conceivable that the processes of growth and multiplication may have taken place without the process of heredity. The fact that protoplasmic sulphur is almost entirely of cytoplasmic origin seems to show that it does not form any part of the specific germinal pattern since the latter is confined entirely to the nucleus.

The percentage elementary composition of proteins will also give some indication of the chemical structure of living matter. If we assume that there are no prosthetic groups present, then a single spirazine triplet, or a number of them arranged so as to form polygonal compartments, will have approximately the empirical formula $C_{12}H_{24}N_6O_6$ and the following percentage-composition:

C	H	N	O
40.2	6.7	23.4	26.2

As might have been expected, the carbon is too low and the nitrogen too high. This is evidently due to the fact that in the chemical structure of proteins there will be many prosthetic groups contained in the polygonal compartments because the spirazines were not formed from pure glycine but also from other amino acids whose structural formulas have already been given. If we assume that the polygonal compartments are substantially filled with such prosthetic groups, so that each compartment will contain about seven additional carbon atoms as seen in transverse section, then the empirical formula will be approximately $C_{10}H_{14}N_6O_8$ and the percentage-composition as follows:

C	H	N	O
51.7	7.7	19.0	21.2

The agreement between these values and the experimentally-obtained values in the following table is about as close as can be expected from an approximate calculation of this sort:

PERCENTAGE ELEMENTARY COMPOSITION OF PROTEINS

	C	H	N	S	O
Egg Albumin	51.5	6.76	18.1	0.96	22.7 -
Casein	53.0	7.00	15.7		22.7 -
Edestin	51.5	7.04	18.7	0.88	21.9 -
Fibrin	52.9	6.90	16.6	1.18	22.4 +
Gelatin	49.4	6.80	18.0	0.70	25.1
Gliadin	52.7	6.86	17.7	1.03	21.7 +
Hemoglobin	54.8	7.00	17.2	0.65	19.9 -

It appears from the foregoing that living matter consists largely of duplications of the same or similar chemical structures, and that the unit of structure cannot be

much larger than a spirazine triplet. In fact, we may even regard the individual spirazine as the unit of structure. Since all spirazines are composed of the same sequence of carbon and nitrogen atoms, it appears that there must be a definite limit to the chemical complexity of living matter. We should not confuse manifoldness of structure with intrinsic chemical complexity. The number of variations which can be produced in the cross-sectional patterns of clusters of spirazines by changing the connections of the spirazines with one another is enormous, and variations of this sort in the nuclear structures of the germ cells may result in all sorts of complex changes during subsequent embryonic development, but the complexity is in the biological significance of the pattern as a whole and not in the chemical behaviors of its component parts. Since a spirazine triplet, as seen in transverse section, is no more complex than many of the organic molecules which have been synthesized and studied by chemists, we may confidently expect that the gap which has heretofore existed between chemistry and biology will soon be completely bridged over, and that a satisfactory mechanistic explanation of all phases of vital activity will soon be forthcoming.

In the accompanying diagrams it has been possible to represent the chemical framework of living matter only in its statical aspect, but it should be constantly borne in mind that the various units of living matter are not rigid crystalline structures but plastic chemical fabrics which are almost continually in a state of metamorphosis and that it is the specific behavior of living matter and not its exact form or appearance which is carried on through successive generations. It is impossible to represent adequately on paper the various deformations of which the spirazine structure is capable, but it should be noted that besides mere flattening out of the fabric in one direction or another, there is also the pos-

sibility of longitudinal straightening out of the spirazines themselves which may take place without any severance of the peptide linkings, so that almost every conceivable change of shape is possible without any mutilation of the pattern which is characteristic of the species.

Living matter differs from dead matter not so much in its chemical constitution as in its behavior. Dead matter, regardless of its origin, is always indifferent in its behavior, whereas living matter behaves as though it had a definite purpose. For example, if two masses of dead protein material be brought into contact with each other, neither will have any advantage over the other and both will remain inert. However, if one of these masses be brought near a living cell, it will be gradually digested and assimilated by the latter. Now, if this were an ordinary chemical reaction, then the chemical affinity of the living cell for the amino acid radicles of the dead protein material would be satisfied after the first layer of radicles had been assimilated, but actually the cell is just as hungry afterwards as it was before.

There is only one artificial process which shows a similar behavior, and that is electrolytic deposition. No matter how many ions have already been deposited electrolytically, there is a constant effort to deposit more, even from dilute solutions. The assimilation of food-materials by living cells can therefore be explained if it can be shown that such cells can generate electric potentials. It has already been shown that living matter consists of a delicate chemical fabric, and it is entirely possible that its interstices may be of just such a size as to permit the small positive hydrogen ions to escape freely, but not the larger negative ions. The latter, including principally the carbonate and lactate ions, will therefore accumulate within the protoplasmic fabric so as to build up negative electric potentials.

Some of the carbonate ions or carbonic acid molecules within the growing protoplasmic structures may migrate away and get lost, but these will be replaced by oxidation of carbohydrates. The carbonic acid molecules thus produced will be carried by the protoplasmic circulation into the polygonal passageways of the spirazine clusters. Since these passageways are of the order of molecular dimensions and are bounded on all sides by groups of similarly constructed spirazines, the atoms or groups of atoms which form the walls and margins of such passageways will permit only the smaller particles such as the hydrogen ions to pass through, and may also behave like Maxwell's demons so as to close or open such passageways according to whether the approaching molecules or ions are of one kind or another. A selective sorting out of the entrapped or surrounding material may therefore be effected so that only certain kinds of particles will find their way through the protoplasmic fabric.

These negatively electrified portions of living matter will attract and form peptide linkings with the exposed amino acid radicles of any particle of dead protein material in their immediate neighborhood, and when such particle again breaks away it will leave the exposed amino acid groups behind to form parts of the living structure. Any amino acid radicle which is thus assimilated will arrange itself with the amino group directed inwardly toward the living structure and with the carboxyl group directed outwardly. Active assimilation therefore takes place only at the carboxyl ends of the spirazines. The amino ends are probably in chemical combination with the phosphoric acid radicles of nucleotides in other portions of the cell. Since spirazines are so constituted that their external chemical configurations are not changed by the addition of amino acid radicles

thereto, this process of assimilation should be able to repeat itself any number of times.

As a result of this negative electrification of certain portions of the protoplasmic fabric there will also be an accumulation of other positive ions, especially potassium, to take the place of the lost hydrogen. Although sodium may be more abundant than potassium in the surrounding medium, yet the potassium ion, perhaps because of its greater mobility, will accumulate more rapidly in the living cells. Some of the larger anions such as the sulphate ion are also rarely present in living cells although they may be abundant in the surrounding medium.

Biological oxidation of carbohydrates ordinarily results in the production of carbon dioxide and water, but during the formation of neoplasms and during vigorous exertion of any sort there will also be considerable production of lactic acid. This will result in a further increase of negative potential within the cell-structure, not only because the lactate ion is larger than the carbonate ion and therefore not so liable to escape, but also because lactic acid is more highly dissociated than carbonic acid so that it will produce a greater concentration of hydrogen ions. This increased negative potential will not only result in more rapid assimilation of amino acids but will also cause the accumulation of more potassium ions. These will cause greater osmotic swelling so as to further distend the protoplasmic fabric and thus expose a greater portion of it to the surrounding nutrient material, which will again result in further assimilation of amino acid radicles. The new structures thus produced will then develop negative potentials of their own, and thus the process will continue until it is checked by inhibitory influences or death.

In the ideal case just considered there resulted only the building up of a single fibrous or cylindrical struc-

ture, but in cases where the clusters of spirazines are arranged and interconnected according to more complex patterns, new morphogenetic activities will appear and new behaviors will be manifested, but the dominant governing motives will remain the same. There will in each case be a persistent striving of the organism to preserve its integrity and to complete and perpetuate its structure. This is not the result of any large-scale anatomical organization but is inherent in the individual spirazine clusters of which every living cell is composed.

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CHAPTER VII

CELL-DIVISION AND HEREDITY

"If we possessed a thorough knowledge of all parts of the seed of any species of animal (including man), we could from that alone, by reasons entirely mathematical and certain, deduce the whole figure and conformation of each of its members and, conversely, if we knew several peculiarities of this conformation, we could from these deduce the nature of its seed."

RENE DECARTES, 1596-1650.

"Where a cell exists there must have been a preexisting cell, just as the animal arises only from an animal and the plant only from a plant. The principle is thus established, even though the strict proof has not yet been produced in every detail, that throughout the whole series of living forms, whether entire animal or plant organisms, or their component parts, there rules an eternal law of continuous development."

Cellular Pathologie by R. VIRCHOW, (1858).

"Inheritance must be looked at as merely a form of growth."

Variation of Animals and Plants under Domestication by

C. DARWIN, (1868).

Every living organism exhibits during some period of its existence the phenomenon of cell-division, which may take place either by simple fission as in the case of bacteria, by budding as in the case of yeasts, by direct amitotic division of the nucleus as in the case of pathological growths or tissues of a transient nature, or by mitotic division of the chromosomes either with or without the formation of centrosomes and asters as in the case of nearly all higher plants and animals.

It has been suggested that cell-division may be due to the fact that as an organism becomes larger its food requirements increase as the third power of its linear

dimensions whereas the quantity of food within reach increases only as the first or second power. This explanation seems to be inadequate because shortage of food would only cause an organism to become undernourished, which might retard its growth and eventually result in its death, but would not cause it to divide. Attempts to explain cell-division on the basis of food-economy have been due to a confusion of the principles of phylogeny with the principles of ontogeny. It may be true that division of a large cell into smaller ones has its economic advantages and gives the species a better chance to survive, but that does not explain what causes the actual separation of the cell into two halves.

It has also been suggested that cell-division may be due to the fact that as an object grows larger it may become physically unstable, due to the fact that its surface, which contributes to its stability because of surface tension, increases only as the second power of its linear dimensions, whereas its volume, which contributes to its instability, increases as the third power of its linear dimensions. Such an explanation is also inadequate because the mere presence of a large mass or volume would not cause an object to divide into fragments unless it be acted upon by external forces, and it has never been shown that physical disturbance is necessary for cell-division.

Neither can cell-division be attributed to surface tension because the effect of surface tension is always to hold a body together and never to separate it into fragments, but even if surface tension would act in a direction opposite to that in which it actually does act, it would still be insufficient to account for cell-division because the cohesive strength of protoplasmic fibers is far greater than any force that could possibly result from surface-tension. For example, a single human hair will sustain a tension of about 40,000 dynes, whereas a fila-

ment of physiological salt solution of the same dimensions will sustain a tension of only about one dyne.

Neither can cell-division be explained on the same theory as peptization of colloids because cell-division will repeat itself an unlimited number of times in the same environment, whereas peptization takes place only upon change of conditions, as by addition of a peptizing agent, and then proceeds only towards a new state of equilibrium.

There are many reasons for believing that the forces which cause a cell to divide arise from within and not from without, and that a heterogeneous internal structure is necessary for this purpose. Objects such as crystals which are internally homogeneous will not ordinarily divide spontaneously if their environment is not changed, and in those exceptional cases where spontaneous division of crystals does occur it is probably due to a slight amount of internal heterogeneity resulting from defects in the crystal-structure. If cell-division were the result of external forces such as surface tension then division should commence with the outermost portions of the cytoplasm whereas actually it commences with the innermost portions of the nucleus, and sometimes, as in the case of certain cartilage-, bone-, and muscle-cells, it does not involve the cytoplasm at all.

The true cause of cell-division seems to be intimately associated with the spirazine structure of living matter. In order to perpetuate the pattern which is characteristic of the species, we must assume that division takes place in a plane perpendicular to the spirazines; and in order to replace by subsequent growth what was lost by division, we must assume that growth takes place in a direction longitudinally of the spirazines. The cohesion of a cluster of spirazines in a direction longitudinally of the

latter must be due principally to the spirazines themselves; and since the number of spirazines in such a cluster remains constant during growth, the cohesive strength thereof must also remain constant. The efforts of the spirazines to hold the structure together will be opposed by the mutual repulsion of the continually increasing accumulation of prosthetic groups such as fat or lipoid radicles, and as soon as the cohesive strength of the spirazines is overcome the structure will divide into two halves. The same result may also be produced osmotically. As the accumulation of prosthetic groups increases there will be an increased accumulation of negative or acid ions in the interiors of the spirazine clusters due to loss of hydrogen ions, and this gradual change in the electrochemical condition of the entrapped material may eventually bring about disintegration of the peptide linkings near the center of the structure where division usually occurs.

There is an abundance of evidence that the large majority of nucleated cells are not merely arbitrary subdivisions of living matter or mere aggregations of smaller living units, but are equipped with a unique internal organization which is substantially the same for all species of plants and animals. This internal organization is exhibited most clearly by the arrangement of the chromosomes about the spindle during mitotic cell-division, which always passes through the following stages:

(1) The *Prophase*, (30 to 60 minutes), during which the irregular network of the resting nucleus organizes itself into a lightly-staining thread or spireme which soon thereafter splits longitudinally into two closely adjacent halves, gradually increases its affinity for basic dyes,

contracts and thickens, and at the same time breaks up into separate chromosomes. The centrosomes and asters at the same time move away from each other toward opposite sides of the cell, and finally the nuclear membrane disappears.

(2) The *Metaphase*, (2 to 10 minutes), during which the chromosomes divide longitudinally if they are not already divided, and arrange themselves in a transverse plane midway between the centrosomes. At the same time the spindle is formed and the two halves of each chromosome attach themselves in a unique manner to the spindle-fibers.

(3) The *Anaphase*, (2 to 3 minutes), during which the daughter-chromosomes move toward opposite poles of the spindle. This operation takes place rather quickly and is always furthest advanced at the points of attachment to the spindle-fibers.

(4) The *Telophase*, (3 to 12 minutes), during which the two groups of daughter-chromosomes, which have now arrived at the opposite poles of the spindle, become reconstructed into the resting-nuclei, while the cytoplasm undergoes cleavage. At the same time the two halves of each centrosome begin to move away from each other in preparation for the next cell-division.

From the above information alone it would be difficult to arrive at any definite conclusions concerning the mechanistic details and chemical changes involved in mitotic cell-division, but the following additional facts will be useful for testing the correctness of any proposed theory:

(1) During mitotic cell-division, if cleavage is symmetrical, the protoplasm flows superficially toward the equatorial plane from both sides so as to form a double vortex with the adjacent sides flowing inwardly toward the center.

(2) A centripetal flow of hyaloplasm takes place in the astral rays and accumulates in the astral centers.

(3) Cytoplasmic cleavage may be either by constriction as in the amphiastral type of mitosis which is characteristic of the higher animals, or by cell-plate formation as in the anastral type of mitosis which is characteristic of the higher plants.

(4) Each chromosome has its own specific mode of attachment to the spindle-fibers which is the same from generation to generation but may be different for different individuals of the same species.

(5) The daughter-chromosomes move away from each other most rapidly at the points where they are attached to the spindle-fibers.

(6) The nucleus and chromosomes may divide without any division of the cytoplasm as in the formation of plasmodia and syncytia.

(7) The chromosomes may divide without division of either the cell-body or the centrosomes as in artificially-induced monocentric mitosis.

(8) The chromosomes may divide in the entire absence of the centrosomes as in most of the higher plants.

(9) A cell deprived of its nucleus has lost the power of protein synthesis, growth, and repair, although it may still be capable of photosynthesis, carbohydrate oxidation, food ingestion, and coordinated movements.

(10) Chromosomes are electrically negative whereas cytoplasmic material is electrically positive.

(11) The central bodies are sometimes within the nucleus, as in some of the protista.

(12) Spindle-fibers may develop separately without centrosomes or asters, as is common in protista and nearly all plants. They may develop entirely within the nucleus as in the vegetative cells of certain plants.

(13) Central bodies may appear *de novo* from cytoplasmic material as when unfertilized eggs are shaken to

pieces and treated with certain salt-solutions. The egg-fragments, whether nucleated or non-nucleated, will spontaneously develop centrosomes and asters.

(14) The formation of an amphiaster from a single aster does not take place by direct division but by a complete dissolution of the single aster followed by reconstruction of its material into two new asters about the original centers.

(15) The centrosomes and asters may undergo many successive divisions in the entire absence of nucleus or chromosomes, as when all the chromosomes are caused to pass to one pole or are removed artificially.

(16) The astral rays frequently intersect and cross one another and are sometimes observed to push the nuclear membrane inwardly so as to give them the appearance of rigid structures.

(17) The amphiaster can rotate or move freely in the cytoplasm, either under normal conditions or under micro-manipulation.

A complete explanation of the mechanism of cell-division will not be possible until more information is available on the chemical constitutions of the various cell-structures, but the following conclusions seem to be reasonably certain:

(1) Growth and cell-division are under central control from the nuclear regions.

(2) The nuclear membrane, with the resulting differentiation of cellular material into nucleoplasm and cytoplasm, is only of secondary importance and is not primarily responsible for growth and cell-division.

(3) The pattern which is characteristic of the species is located in the nuclear regions, although the specific

cytoplasmic organization may depend on the form of this nuclear pattern.

(4) Spindles and asters are formed during certain stages of cell-division by precipitation from the fluid protoplasm, and subsequently disappear by dissolution in the same fluid. They are not autonomous or self-perpetuating bodies.

(5) There is a close relationship between the internal structural organization of a cell and the form of vortex generated by the flowing protoplasm.

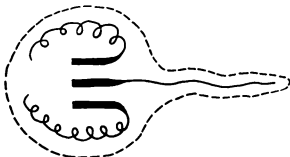


FIG. 16. Diagrammatic illustration of the internal organization of a unicellular organism just prior to cell-division.

In the diagrammatic illustrations on Figs. 16 and 17 there is shown a simple example of how the specific heterogeneous structure of a parent cell may be transmitted by heredity to the progeny. It is not contended that these illustrations are complete and true to fact in every detail, but they are thought to represent a sufficiently close approximation of what may actually take place in nature to justify their presentation as a working hypothesis, with the understanding that alterations and additions may be made as our knowledge of the subject increases.

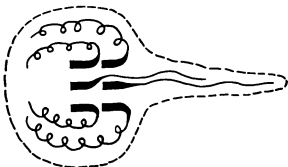


FIG. 17. Diagrammatic illustration of the internal organization of a unicellular organism during cell-division.

In Fig. 16 there is shown a group of three spirazine clusters, the inner or nuclear portions of which are massed together into compact rod-like structures whereas the outer or cytoplasmic portions form threadlike extensions. The inner portions may be assumed to contain the free carboxyl ends of the spirazines and may be regarded as the negatively electrified regions where assimilation of amino acid radicles takes place, whereas the outer portions may be assumed to contain the free amino groups and may be regarded as the regions where carbohydrate metabolism takes place. On account of the differences in chemical and electrical conditions of environment it may be assumed that the inner portions of these spirazine clusters cling together so as to maintain their specific cross-sectional patterns, but that the outer portions become separated from one another and drawn out into irregular masses of fibers. It may also be assumed that the spirazines in the two outermost clusters have different arrangements than those in the central cluster so that the masses of threadlike extensions from these

various clusters will differ from one another in their physical and chemical properties. For example, the threadlike extensions from the two outermost clusters may be so constituted as to become coiled up into irregular masses of cytoplasm, whereas the one from the middle may grow out fairly straight so as to form a flagellum.

When cell-division commences and the clusters divide transversely as shown in Fig. 17, the broken ends of the daughter-clusters will possess the same chemical configurations as the corresponding ends of the parent-clusters had before division. The newly-produced amino ends will form the threadlike extensions, whereas the newly-produced carboxyl ends will divert some of the circulating fluid into a new vortex and will acquire negative electric charges. A new cytoplasm with a new flagellum will develop alongside the old one, and after the two structures have become functionally independent and structurally distinct they will constitute exact duplicates of the parent-cell.

In Figs. 16 and 17 the cytoplasmic fibrils have been represented as continuations of the nuclear spirazine clusters so as to clearly indicate their origin, but it should be understood that these fibrils may in some cases become completely separated from the nucleus and may break up into tiny rod-like sections which will then be carried along in the circulating cell-fluid. Bodies of this sort can be observed in the hyaloplasm under high magnification with reflected illumination from above and may constitute the enzymes by means of which food-material is digested and carried to the nuclear spirazine clusters for assimilation, or under other conditions may constitute the building-material from which the asters and spindles are produced.

The flagellated protozoon depicted in the foregoing illustration has been planned out as simple as possible so as not to confuse the reader with unnecessary details,

but it will be readily conceivable that as the complexity of the nuclear structure is increased, the complexity of the cytoplasmic organization will also be increased proportionately. For example, if there would be present thirty or three-hundred spirazine clusters instead of only three, and all different from one another in chemical structure, then there would be no difficulty in accounting for the most complex cell-structures found in nature. For every hereditary feature in the chemical configuration of the nuclear spirazine structure there will be a corresponding hereditary feature in the cytoplasm or soma. The relation of the former to the latter is similar to the relation of the factored form to the expanded form of an algebraic expression. Either of them can be derived from the other, although the two may be totally different in appearance.

During mitotic cell-division the basophilic chromatin-material from the chromosomes spreads out into irregular patches over the surfaces of the newly formed nuclei and gradually disappears, while new sets of chromosomes are being formed inside. This chromatin-material has usually been regarded as the seat of heredity, and to explain its supposed genetic continuity it has usually been assumed, although not supported by a trace of experimental evidence, that at least a portion of it is transmitted to the newly formed chromosomes. However, the fact that it stands out conspicuously in stained preparations does not prove that it plays an important part in vital processes. According to the spirazine hypothesis the seat of heredity must always consist of a coordinated group of spirazines, so that the chromatin-material, which evidently consists of substances in the dissolved or molecular state, can only be regarded as either nutrient- or waste-material and is probably nothing other than

combinations of nucleic acids with basic proteins. When protoplasmic structures are subjected to severe stresses, as must occur in the nucleoplasm during cell-division, there will probably occur a flattening-out or stretching of the polygonal compartments in one direction or another so as to effect the shedding of some of the superficial structures in the form of purine, pyrimidine, guanidine, or urea complexes which can then be liberated in the form of nucleic acids.

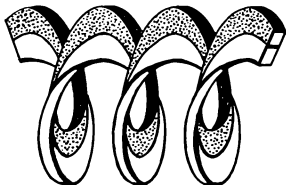


FIG. 18. A reversely twisted helix. The two halves can be completely separated from each other laterally.

There sometimes occurs during certain stages of cell-division a delicately coiled basicchromatin thread, known as the "chromonema," which is arranged as a spiral winding around the spireme-thread or prophase-chromosomes. This chromonema is always very uniform in contour when it is first formed, but usually straightens out and thickens or collects along opposite sides just prior to longitudinal splitting of the spireme-thread or chromosomes. Although the chromonema may consist merely

of waste-material, yet its uniformly convoluted shape does indicate a spiral construction of the nucleoplasm in the region of the spireme-thread or chromosomes, but this spiral structure should not be confused with that of the individual spirazines which are several thousand times smaller. Ordinarily when an elongated member is coiled around in the form of a spiral and is then divided longitudinally the two halves cannot be separated from each other laterally but will remain linked together. Since the spireme threads or prophase chromosomes become separated from each other completely after longitudinal splitting, they could not have been formed in this simple manner but must have had a construction similar to that shown in Fig. 18, wherein the thread itself is twisted in a direction opposite to the direction in which the coil is wound. Regardless of whether this structure remains in the form of a coil or is drawn out straight, the two halves can be completely separated from each other laterally.

There are two different kinds of heredity. The major anatomical characteristics by which the different species of plants and animals are distinguished from one another reappear from generation to generation and remain unaltered until there is some permanent change in the characteristics of the species. When such a change does take place it is generally irreversible and not governed by Mendel's laws, from which it appears that the corresponding alterations in the spirazine pattern of the germinal material must also be irreversible. Such alterations may consist of changes in the total number of spirazines or in their arrangements with respect to one another. On the other hand, there are certain minor characteristics, such as the colors and textures of the various body-tissues, which may change freely from

generation to generation in accordance with Mendel's laws without involving any permanent change in the nature of the species. Such minor changes take place with equal facility in either direction, from which it appears that the corresponding variations in the germinal material must be readily reversible and must be confined to local changes only, such as the coupling or uncoupling of the adjacent spirazines through their carbonyl and amino groups, so as to permit that peculiar allelomorphism which is characteristic of Mendelian heredity but without involving any permanent change in the spirazine pattern as a whole.

Any feature which is transmitted by Mendelian heredity will appear either completely or not at all. It will ordinarily make its appearance to exactly the same extent regardless of whether only one or both of the gametes contain the positive or dominant characteristic. This can be explained only on the theory that the physiologically active agents in such a case are not the dominant spirazine-clusters themselves but certain hormone- or enzyme-like substances in the dispersed or molecular state which were liberated therefrom. These may have an accelerating or inhibiting effect upon the morphogenetic activities of the spirazine-clusters, but are not themselves morphogenetic. If either one or both of the gametes contain the dominant characteristic, then the above-mentioned substances will be liberated and will produce their specific effects.

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CHAPTER VIII

ONTOGENETIC DEVELOPMENT

"Matter is not without its forms, but contains them all; and since it carries what is wrapped up in itself, it is, in truth, all nature and the mother of all the living."

GIORDANO BRUNO, 1548-1600.

"It is not the organs, i.e., the nature and form of the parts of the body of an animal, which give rise to the special habits and faculties, but, on the contrary, its habits, its mode of life, and the circumstances in which individuals are placed, which have, with time, brought about the form of its body, the number and condition of its organs, finally the faculties which it possesses."

JEAN LAMARCK, 1744-1829.

"It is as if fertilization explosively and mysteriously lifted a pendulum to its highest summit and the rest of life were the story of the gradual decrease in the amplitude of its swings. In this sense the law of degradation of energy describes the life process itself; it satisfies the mathematical, esthetic, and sensational predispositions."

Physiological Ontogeny by H. A. MURRAY, (1927).

In the simplest unicellular organisms the life-cycle is complete after each cell-division, but in the higher organisms there is also the larger life-cycle of the organism as a whole. It is a significant fact that this larger life-cycle with its extensive diversification of tissues occurs only in those organisms which possess sex. Structures which are formed by aggregation of non-sexual units always exhibit a predominating characteristic of sameness in their make-up, as for example the frost-patterns formed on cold window-panes. Occasionally a branch may grow out in one direction or another, but random growth of this sort can never explain the devel-

opment of an organism like man. The development of a single tissue could probably be explained in this manner, but not the specific manner in which the different tissues are fitted together into cooperative relationship.

It is generally thought that sex is an adaptation by nature for the purpose of promoting certain phases of biological economy or for increasing the variability of the species, but these assumptions are not adequately supported by facts. Division of labor and specialization of function seem to be the results, rather than the causes of sex-differentiation, so that sex cannot be attributed to matters of economy. Neither can its purpose be to increase the variability of the species because the variations which can be brought about in non-sexual organisms like bacteria by growing them upon different kinds of nutrient material are much more pronounced than similarly produced variations in any of the higher plants or animals.

The real reason for the existence of two sexes seems to be that embryonic development cannot ordinarily be brought about in nature in any other manner than by reduction-division of the chromosomes, followed by fertilization. In order to produce in their proper order the various kinds of cells which are needed for the building up of the embryo, the gametes must be subjected to an internal disruption of such magnitude that the ensuing processes of readjustment will continue throughout many subsequent cell-divisions. These operations may be likened to the operation of a clock which has to be wound up to cause the hands to move around; but just as a clock requires not only a wound-up mainspring but also a special internal mechanism to cause the hands to move in the required manner, so also the gametes must not only have united to form the zygote but must also be in possession of a specific internal chemical structure in order that the successive divisions of the zygote will

be so timed, proportioned, and otherwise characterized as to produce the embryonic tissues in the required co-operative relationship to one another.

The explanation of the complex and purposeful activities of the higher forms of life is often difficult to present in a simple and direct way, but can be rendered more comprehensible by expressing such activities in terms of the following three factors which seem to include all the fundamental life processes: (1) The striving of living matter to preserve its integrity and to complete and perpetuate its structure; (2) The transmission of complex anatomical structures by heredity through the germ-cells; (3) The accumulation of mnemonic records of past experience.

The natural striving of every living organism to promote its own interests originates in the activities of the individual spirazine clusters, which activities are combined and in many cases amplified to produce the behavior of the organism as a whole. The specific anatomical organizations of the higher plants and animals in which these processes of combination and amplification must take place will not permit the manifestation of these activities in their simple original aspects, but will give expression to them in the form of specific modes of physiological functioning. Although the striving of the individual spirazine clusters to preserve and perpetuate themselves is a uniform and continuous process, yet the corresponding efforts of the organism as a whole are being constantly modulated and altered, not only in accordance with the physiological conditions which exist during the various stages of ontogenetic development, but also in accordance with the mnemonic accumulations from past experience.

The existence of a direct causal relationship between the present and the future during ontogenetic development must be assumed for the sake of rationalism, but it is not necessary to assume that such causal relationship is in consequence of any mysterious teleological activity or conscious foresight into the future. It is one of the cardinal principles of the mechanistic theory of life that for every function there is a prerequisite structure specifically adapted for that purpose. Consequently if the spirazine theory will explain the orderly and systematic development of living structures, then the corresponding functions which result from the exercise of such structures will also be accounted for. In some cases the structural basis for a certain function is purely physical or anatomical so that the relation between structure and behavior will be apparent; but there are other cases where such structural basis is essentially chemical and therefore hidden from direct observation so that present activities will appear to be entirely arbitrary except in so far as they bear significance with respect to future needs.

In order to preserve the life of the individual and to ensure the survival of the species it is necessary that any hereditary characteristic which does not make its appearance until an advanced stage of ontogenetic development should be in harmonious relationship with all previously acquired characteristics. The presence of any characteristic which is incompatible with the pre-established order of ontogenetic development would be detrimental to the welfare of the individual and would contribute to the extinction of the species. The existence of this harmonious relationship between the various stages of ontogenetic development makes the whole process *appear* as if it were the result of intelligent prevision, but upon more thorough investigation of the underlying causes of ontogenetic development the teleological aspect thereof will vanish.

The inherent tendency of living matter to develop more complex structures and to perpetuate any structure which is once acquired has already been associated with the possible folding-over of individual spirazines, and may also be due to a permanent recombination of living matter with its own enzymes so as to enlarge the spirazine pattern. These enzymes probably consist of spirazine clusters which have become separated from the original protoplasmic material but whose chemical structure is not such that they can grow and reproduce. Since the hereditary characteristics of living cells are not changed by the separation of enzymes therefrom, it appears that such separation must take place in directions longitudinally of the spirazine clusters; but since the hereditary characteristics may be changed by recombination with such enzymes, it appears that such recombination must take place along the sides of the spirazine clusters so as to enlarge the patterns. The actual union probably takes place between certain carbonyl and nitrogenous groups which originally held the enzyme-structures attached to the cell-structures. The distance between any two of these groups in the enzyme-structure will be the same as the distance between the complementary groups in the cell-structure because both structures carry the same spirazine pattern, and it is probably this equality of distances which makes the two structures biochemically specific to each other.

There is an abundance of evidence that those characteristics which are developed in the higher forms of life by voluntary and prolonged efforts of the individuals are apt to become hereditary in the course of time. This may be due to the liberation, from the cells of the vigorously-exercised tissues, of certain enzymes which will be chemically specific, not only to the tissues from which they were produced, but also to the corresponding chemical structures of the germ-cells so as to combine

with or activate the latter. In this manner there may be brought about an augmented production, during succeeding generations, of those tissues which have been subjected to the most vigorous use during the adult stages of the preceding generations, and although such augmented production will appear to be a purely teleological activity in preparation for future use by the next generation, it will, in reality, be a forced activity brought about by the addition, during previous generations, of certain chemical structures to the germ-cells.

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CHAPTER IX

MENTALITY AND CONSCIOUSNESS

"Why, if the Soul can fling the Dust aside,
And naked on the Air of Heaven ride,
Were't not a Shame—were't not a Shame for him
In this clay carcase crippled to abide?"

The Rubaiyat of OMAR KHAYYAM, 1-1123.

"The soul is formed, it grows and decreases with the organs
of the body therefore it must also share in the latter's death."

J. O. DE LA METTRIE, 1709-1751.

"The more one studies all the intellectual faculties, the more
convinced one remains that they are all included in the faculty
of sensation, upon which they all depend so essentially that with-
out it the soul could never perform any of its functions."

L'Histoire Naturelle de l'Ame by

J. O. DE LA METTRIE, 1709-1751.

"Those who have distinguished the soul from the body seem to
have only distinguished their brains from themselves."

Le Systeme de la Nature by

P. H. D'HOLBACH, 1723-1789.

"The so-called proofs of immortality are all worthless—not one
of them will stand the light of modern science. The theological
proof—that God breathed an immortal soul into man's body—is
a myth, pure and simple. The cosmological proof—that immor-
tality is a moral necessity—is without any rational basis. The
teleological proof—that man must forge ahead into a perfection
which this life is too short to attain—is a baseless dogma. The
moral proof—that the good man who suffers here must be re-
warded somewhere else—is simply a pious wish. The ethnological
proof—that belief in immortality is innate in all peoples every-
where—is simply a misstatement of fact. The ontological proof—
that the soul is non-material and hence not subject to decay as

matter is—rests on a fallacious conception of the nature of psychic phenomena." (Summarized by V. Randolph.)

Die Welträtsel by E. H. HAECKEL, 1834-1919.

The metaphysical attributes of living organisms have been given various designations such as spirit, soul, mind, and instinct, but will be referred to hereinafter as "mentality" or "consciousness." These designations are sufficiently general to be applicable to any protoplasmic system having specific unitary organization. They must be regarded as merely the necessary manifestations of certain functional activities of the kind that take place in living matter and not as fluids, vibrations, or other self-contained entities because there is no satisfactory evidence that the mind can reach out and act beyond those chemical structures in which it originates, or that it has continuity of existence in any form whatever after the death of the individual.

It is generally thought that mentality and consciousness are possessed by only certain of the higher animals, but when we observe the energetic and purposeful movements of many of the simplest protozoa it seems difficult to justify this conclusion on any sort of a rational basis. Mentality and consciousness are usually predicated upon the responsiveness to stimuli, the spontaneity and arbitrariness of action, and the accumulation of mnemonic records of past experience, but these characteristics are exhibited not only by the nervous and muscular systems of the higher animals but also by the protoplasmic fabrics of the unicellular organisms. For example, if a vorticella is touched the myonemes of the stalk will contract and draw the animal away from the source of irritation, just like the nerve- and muscle-fibers of a higher animal will respond to the touch of a hot object. The characteristic behavior of living organisms is determined by the reactivity of the protoplasm itself which always possesses

substantially the same physical and chemical make-up regardless of the position of the particular organism in the scale of evolution. The elaboration of protoplasmic structures into complex anatomical systems does not change the intrinsic characteristics of living matter itself, and so far as mental attributes are exhibited by protoplasmic behavior they must be regarded as the general heritage of all forms of life.

Mental activity is always accompanied by a condition known as "consciousness." In the medicolegal sense consciousness requires only the *ability* to entertain thoughts or sensations but not necessarily the actual realization thereof. It is doubtful whether it would be possible for any one in the awake condition to become totally devoid of all thought or sensation, but if such a condition were to exist then there would probably be no actual consciousness, that is, a person in that condition would probably not be aware of himself. It appears, therefore, that the term "consciousness" when used in a psychological or philosophical sense should be interpreted to mean only that condition which exists during the *actual* exercise of the mental faculties.

Memory is a necessary prerequisite for both thought and sensation and therefore also for consciousness. That thought must always deal in one way or another with the memory of our past experience is obvious, and there is an abundance of evidence that the realization of a sensation requires not only the conduction of nerve-impulses to the brain but also the presence in the cerebral cortex of a specific unitary organization with mnemonic records of past experience. These records probably consist of alterations in the chemical structures of prosthetic fat, lipoid, carbohydrate, or ureide radicles clinging to the spirazine clusters in the cortical synapses. Altera-

tions of this sort will change the conductivities of the various synapses in such a manner as to direct the incoming sensory impulses into predetermined channels where they will excite specific responses.

Although self-perpetuation by one mode or another seems to be the distinguishing characteristic of living matter, yet it is interesting to note that in the unicellular as well as in the multicellular organisms the exercise of the mental faculties seems to be quite independent of the purely vegetative or reproductive functions. It appears, therefore, that the mechanism which is responsible for mental activity must be distinctly different from the mechanism which is involved in the vegetative and reproductive functions, and no reason is seen why either of these mechanisms could not exist independently of the other. Mental activity involves nothing more than intelligent behavior, and the only conditions prerequisite for such behavior are individuality and memory. Individuality is possessed by every atom, molecule, and self-contained artificial device having a definite system of structure and operation, and memory is nothing different in principle from the effects produced upon such atoms, molecules, or artificial devices by external agencies.

That an atom, molecule, or artificial device cannot possess *human* consciousness is obvious, but what justification would there be for assuming that there cannot exist in nature any other sort of consciousness except what accompanies the exercise of one or the other of our five senses? When an atom or molecule encounters certain electrical conditions it "remembers" the event by becoming ionized. Although the number of different states of ionization which an atom or molecule can assume is not as great as the number of different mental

states which a human being may acquire, and although the duration of the effect may in some cases be for only a millionth of a second instead of for a hundred years or more, nevertheless, these are mere differences of degree and not of kind. Effects similar to memory have also been observed in certain types of machines. It sometimes happens that when a machine which has been operated in a certain way for a long period of time is suddenly subjected to a different kind of use, its efficiency will be temporarily reduced; and when again subjected to the original mode of operation a similar temporary reduction of efficiency occurs. Each time when the mode of operation is changed the machine "remembers" its former mode of operation, which is similar in principle to the effects of changes of environment upon a human being.

There seems to be no logical basis for the contention that consciousness cannot exist in a device which is entirely automatic. For example, a selenium cell connected to a relay by means of an electric conductor has the same principle of operation as the retina connected to the brain by means of the optic nerve, and it is difficult to understand why consciousness should exist in the one case but not in the other. The fact that an automatic device cannot exercise any freedom of will does not prevent it from possessing consciousness because the sensory neurons are also entirely automatic and devoid of free will but are nevertheless endowed with consciousness. In fact, by the use of certain drugs such as curare the motor mechanism may be rendered entirely inoperative without the disappearance of consciousness. It would therefore appear to be more logical to regard consciousness of one sort or another as a necessary attribute of any organized material system, rather than as the special heritage of living matter.

Whether the exercise of free will or volition involves any violation of the fundamental principles of physics and chemistry is a question on which there is much difference of opinion. According to the classical conception of natural law the behavior of every physico-chemical system is completely predetermined, whereas the exercise of free will introduces factors which are arbitrary and self-determined. Since there cannot be two independent systems of governing forces operating in the same place and at the same time, we must either regard free will as a delusion, or we must assume that living matter does not come under the domain of those natural laws which govern physico-chemical systems. Since the existence of free will is being made known to us directly through our consciousness it would be very dogmatic and unscientific to reject the testimony of our consciousness in so far as it furnishes us with a basis for belief in free will, but yet to accept it in so far as it informs us of the operation of the laws of nature. Even if we were to admit for the purpose of argument that free will is merely a delusion, we would still be confronted with the question of why there should be such a delusion.

The laws of physics and chemistry which seem to signify predetermination to the exclusion of free will have their basis in the principles of statistical mechanics. They were derived from experiments upon isolated macroscopic physico-chemical systems and deal only with the effects of simple physical forces or with the combined or average effects of large numbers of atoms, molecules, or other elementary particles of matter. There is no artificial device known which will respond to the specific individual behaviors of such elementary particles of matter, and we cannot extend the laws of physics and chemistry by analogy into the intra-atomic realms where conditions are not the same as those under which such laws were derived.

The elementary particles of matter cannot be isolated and shielded from external influences in the same manner as macroscopic bodies, and being of electric constitution they are not self-contained and have no definite boundaries but consist of certain configurations of electric fields which continually overlap and coact with those of all other material particles. The behavior of each elementary particle of matter will therefore be in synchronism with its immediate surroundings rather than in accordance with the laws of physics and chemistry and will appear to us as being entirely arbitrary and undeterminable, but this does not mean that such behavior is not caused by natural agencies or that it may constitute a channel for supernatural intervention.

It has been suggested by R. S. Lillie that the specific behaviors of the elementary particles of matter may manifest themselves through the medium of living matter. In chemically organized structures of this sort some of the atoms may occupy positions of advantage so that their specific individual behaviors may become amplified sufficiently to effect the excitation of nerve- or other protoplasmic fibers, and it is probably this amplification of the activities of individual atoms which manifests itself as the exercise of free will.

The responsiveness of living matter to the activities of individual atoms can be readily demonstrated by certain optical experiments. After determining the maximum distance from which a small white object can be seen by the light of a candle-flame, and knowing the size of the pupil of the eye, the minimum intensity of light to which the eye is sensitive can then be calculated. Since the radiant energy from one candle-power which falls within the limits of the visible spectrum amounts to about 190,000 ergs per second, the minimum amount of light-energy per one-fifteenth of a second to which the eye is sensitive can then be calculated. It will be found to be

not much greater than 5×10^{-12} erg, which is approximately the amount of energy required to eject one electron from an atom.

In all the higher animals, mentality is coextensive with the central nervous system. Most of the cells of our bodies form parts of us physiologically but not mentally. In order that a cell may form part of us physiologically it is only necessary for it to be definitely coordinated in position and specifically related in function to the other cells of the body; but in order to form part of us mentally it must be coordinated with the cells of the central nervous system on a chemical scale, that is, the channels formed by the polygonal compartments of some integral part of the cell-structure must be in communication, either directly or indirectly, with certain selected channels of the cells of the central nervous system, so that electrochemical impulses traveling along these channels will be transmitted through definite paths to the cerebral cortex instead of being dissipated and lost in the surrounding tissues.

It is a significant fact that thoughts and memories are never transmitted through the germ-cells by heredity. If thoughts and memories were self-contained entities such as chemical substances, then they would be carried by the protoplasmic or blood circulation to all parts of the organism and would eventually find their way into the germ-cells or embryos and be transmitted to the next generation, which has never been known to take place. It appears, therefore, that we must regard thoughts and memories not as substances but as manifestations of the behaviors of certain chemical structures of the central nervous system which have become altered or activated by sensory-impulses during the life of the individual. During embryonic life and for some time thereafter the

effects of such sensory-impulses are rapidly obliterated by cell-division and memory is then of only short duration; but during adult life there is only very little if any cell-division in the central nervous system so that the impressions which are then produced by sensory-impulses will remain for an indefinite time.

Nerve-fibers are similar to other protoplasmic structures in that their interior portions are electronegative with respect to the surrounding medium. This is probably due to spontaneous diffusion of positive hydrogen ions through the interstices in the walls of the fibers, the negative acid ions such as the carbonate, phosphate, and lactate ions remaining behind because they are too large to pass through. The actual difference of potential may be as small as one-fiftieth of a volt, but this is sufficient to actuate a galvanometer having one wire inserted into the cut-off end of the nerve and the other wire touching the nerve from the outside. The nerve-fiber then acts like an electric battery and produces what is known as the "current at rest." What actually happens is that the negative electrons are conducted away from the interior of the nerve, through the galvanometer, and on to the positive hydrogen ions.

A nerve-impulse can be produced by the application of either an increasing negative potential or a decreasing positive potential. In either case there will be a momentary reversal of the "current at rest," from which it appears that the impulse consists of a wave of negative electrification. The excited portion of a nerve may be only one or two centimeters in length, but the impulse may travel as fast as a hundred meters per second. The negative electrification is probably due to a sudden outward migration of negative acid ions through regions of increased porosity. The effect is probably autocatalytic in that the outwardly migrating acid ions will neutralize not only the hydrogen ions immediately opposite

them but also some of the others further ahead, where this progressive neutralization will in turn cause an increase of porosity. In the region immediately behind this wave the electric double layer will be almost completely neutralized so that this portion of the nerve is in a refractory condition and cannot be excited regardless of the strength of the stimulus. This condition, however, lasts only a few thousandths of a second, and after about a hundredth of a second the porosity will again have returned to normal, with the reappearance of the electric double layer.

The transmission of a nerve-impulse involves not only physical but also chemical changes. Oxygen is continually absorbed by nerve-fibers and carbon dioxide given off, not only during activity but also in small amounts while at rest. Nerves will gradually lose both their irritability and their conductivity if kept in an inert medium for several hours, but will regain their activity in a few moments in an atmosphere of oxygen.

Nerve-fibers when artificially stimulated will conduct impulses with equal facility in either direction. The direction of conduction is therefore not determined by the structure of the fiber but by its end-connections. In this respect the behavior of nerve-fibers is similar to the behavior of protoplasmic fibers generally, since in each case the wave of excitation will proceed in all possible directions from the source of irritation.

The cross-sectional structure of a nerve-fiber, if sufficiently magnified, would probably appear somewhat as indicated in Fig. 15. The large interior open spaces will form longitudinal channels and will be bounded on all sides by longitudinal clusters of spirazines. The latter will form the porous side-walls which normally retain the negative acid ions but allow the positive hydrogen ions to escape. Nerve-impulses probably consist of electrochemical waves of longitudinal displacement

transmitted along these spirazines whereby the polar connections between the fourth and fifth valencies of the nitrogen atoms may be momentarily broken. Other changes such as neo-enol or neo-carbinol tautomerism may also occur.

Mere tubular passageways with porous walls cannot, however, constitute the source of mental activity or the seat of consciousness. Neither can mental activity or consciousness originate in the cell-bodies of the sensory-neurons because some of these cell-bodies are entirely separated from the nerve-fibers and can be completely removed therefrom without interfering with the passage of afferent impulses. Although the cell-bodies of the motor-neurons are usually arranged directly in the paths of the nerve-fibers, yet there is no indication that they take any active part in the generation of impulses and are probably only nutrient-centers.

The only structures in which mental activity and consciousness could possibly originate are the end-organs and the synapses, especially the dendritic fibrils of the cerebral cortex. Although a nerve-fiber is concerned only with simple straight-forward conduction along a predetermined path, yet a synapse forms a threshold of varying resistance which may arbitrarily either facilitate or block the passage of impulses. There are millions of synapses in the supra-granular or molecular layer of the cerebral cortex and they constitute a chemical network of enormous complexity in which the various mental concepts probably have their physical counterparts. When an impulse from a sense-perception enters the cerebral cortex the delicate chemical structures of some of the synapses are probably ruptured or remodeled so as to regenerate or facilitate the transmission of similar impulses in the future. These will manifest themselves as thoughts or memories, unless they find an outlet through the motor-nerves, in which case they will manifest themselves as acts of volition.

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